Royal School
of
Bridges and Roads

1842 – 1843

Notes taken during the railway course (1842 – 1843)

Lessons given at the School of Bridges and Roads, aiming to describe the works carried out on the Paris to Orléans railway, and some general considerations on railways.

1st Lesson

The lessons which follow do not aim to be a complete course on railways, but solely the description of the works of the Paris to Orléans railway, along with some general considerations.

General Ideas on the Operation of a Railway.

The first thing to consider is the locomotive. The weight of locomotives has varied greatly: originally they weighed 6 tons; their weight was successively increased to 8, 10, and 12 tons; those for Corbeil weigh 15 tons, and those for Orléans will weigh nearly 16 tons.

Behind the locomotive is the tender, a carriage that carries the water and coke necessary for supplying the machine. Like the locomotives, the weight of the tenders has varied; those on the Paris to Orléans line have six wheels and weigh 10 tons when fully loaded. They usually contain 4 cubic meters of water and 500 to 600 kg of coke.

Passenger carriages are of three classes: diligences, wagons, and open wagons. These carriages, when empty, weigh on average 3500 kg. They contain 24 to 36 passengers, such that when loaded, their weight is about 5 ½ tons.

Baggage wagons weigh – loaded – about 5 ½ tons.

Flour and merchandise wagons weigh 6 tons, including load.

Post-chaise wagons weigh 5 tons.

Stable-wagons for livestock transport weigh 4 ½ tons, including the load.

The track has a width of 1.44 m between the inner edges of the rails. This dimension has, to this day, been uniform for all major railways in France.

Track switches are used to move the engine from one track to another. The same track should, as much as possible, only ever be used in the same direction: there is the inbound track and the outbound track. Switches are operated by means of movable points that are brought closer or moved further away, depending on whether one wishes to switch tracks or stay on the same one. This operation requires, for certain switches, the presence of a man called a switchman. It depends on him alone, and not on the engineer, which track is taken.

To move from one track to another that forms a certain angle with the first, a turntable is used. This is a cast-iron plate that carries one or two tracks and is large enough to carry the wheels of the carriage. This plate rests on a movable carriage, like itself, around a vertical axis.

Without going into the detail of the steam engine, we will only mention what is particular to the locomotive. The locomotive consists of a steam engine and two driving wheels of large diameter (5 to 6 English feet); the axle has two right-angle cranks forming two types of crank handles: the piston rod acts on the end of the crank by means of a connecting rod. A rotational motion is thus communicated to the driving wheel; since it cannot turn on itself, by virtue of the friction of the wheel on the rail, it moves forward. If, however, the load the engine has to pull exerts an effort on it greater than the friction of the wheel on the rail, the engine would not advance and the driving wheels would spin in place. There are two cranks because with only one there would be a moment when the connecting rod would have no effect in producing the motion. These cranked axles are difficult parts to build in locomotives; but they cannot be avoided to allow passage for the connecting rod. The axle is fixed to the wheels; the two or four other wheels of the engine turn by virtue of the connection that the system establishes between them and the two driving wheels.

Calculations on the locomotive in order to give a clear idea of the work it provides. We will adopt the notations of Mr. Guyonneau de Pambour, who is the author of the theory on the locomotive that we will develop here:

m (tons)	weight of the locomotive engine;
M (tons)	weight of the train, including the tender;
K (Kilograms)	coefficient of friction per ton; (K = 2.70 kg) that is to say that if a cord passing over a pulley is attached to the carriage, the weight necessary to set the carriage in motion will be K kg per ton.
g (millimeters meters Kilograms)	this is the gradient in millimeters for[(*)] meter that the track may have at the point considered. g in meters expresses the slope per kilometer. g expressed in kilograms is the effort due to gravity along the gradient for the weight of one ton.
V (Kilometers)	speed of the train per hour.

The first question we propose to solve is this:

When a train is in motion and has acquired a uniform speed, determine the effort exerted by the engine? Or in other words, suppose the train is in motion, detach for a moment the tender and all the carriages, and find the weight which, attached to a cord passing over a pulley, would produce on the engine the same effect as the train.

(*) In the manuscript, it is clearly written millimeters for meter.

Let X be this weight, expressed in Kilograms.

If the track is horizontal,

$$X = KM$$

If the track is inclined,

$$X = KM \pm gM \pm gm$$

taking into account the weight m of the locomotive. The + sign corresponds to an ascending gradient, the - sign to a descending gradient.

If we take into account air resistance, which had long been neglected and which nevertheless produces a notable resistance, a new term must be added. It has been evaluated by experiment; it is proportional to the square of the speed. We thus have:

$$[\,1\,] \quad X = KM \pm gM \pm gm + uv^2$$

Application. Let there be a train of 12 carriages, on a level track. The terms gM and gm disappear from the equation. Taking for the weight of each carriage 5.5 tons and 10 tons for that of the tender, M = 76 tons and as K = 2.70, we will have $K\,M$ = 76 x 2,70 = 205.2 kg.

Let us now evaluate air resistance. We will assume the air perfectly still. If there is wind, it must be taken into account, either positively or negatively. u is proportional to the surface that the train presents to the air, Σ being this surface, we have:

$$u = a \sum$$

a is, in Kilograms, the resistance offered by the air to a surface of 1 square meter moving at a speed of 1 Kilometer per hour.

$$a = 0^k\,,0064$$

As for Σ, here is how it is estimated: w being the number of wagons in a train, including the tender and the locomotive, we have:

$$\sum = (6 + w)^{m.\,s}$$

$6^{m.s}$ is the excess surface that the first wagon or the engine presents over the other wagons, and it is then assumed that the air resistance per wagon, tender, or engine, produced either on the wheels and axles, or on the exterior surfaces of each car, by virtue of the day that separates them from each other acts on a surface of $1^{m.s}$.

The term uv^2 thus becomes:

$$uv^2 = 0{,}005064\,(6 + w)\,v^{2.}$$

In the case we are considering where w = 14 and where the speed is 40 kilometers per hour, we have uv^2 = 162 kg and consequently

$$X = 367^{\,K}$$

Thus, the engine is in the same situation as if a weight of 367 kg were attached to a vertical cord passing over a pulley and this cord, having become horizontal, were then attached to the engine; it would have to lift this weight at a speed of 10 leagues or 40 km per hour.

To these resistances that the engine must overcome, its own friction must be added. This is an excess of resistance that can also be represented by a weight placed behind the engine.

Let F be the friction of the various parts of the engine when it operates alone and without a load to pull; we have, according to Pambour,

$$F = 6{,}70 \times m \qquad \text{or if one prefers,} \qquad F = 7\ m\ .$$

There is reason to review this way of evaluating F and to modify it, current machines being very different from those on which Pambour operated; but the aim here is rather to give a clear idea of the engine and of how its work should be accounted for, than to provide perfectly accurate coefficients for practice; the task of carrying out the necessary experiments, so difficult and delicate, for the exact determination of these coefficients is left to others.

The friction of the engine also increases proportionally with the load it pulls, and it can be fully evaluated by the formula

$$F + \partial\, X$$

∂ being a constant coefficient which, according to Mr. de Pambour, is 0.14 for engines with two driving wheels and 0.21 for engines with four driving wheels.

Denoting by Y the total sum of resistances that the engine has to overcome, we have

$$[\,2\,] \qquad Y = F + (1 + \partial)\, X\ .$$

and in the previous application, assuming that the engine weighed 15 tons like those for Corbeil, we will have

$$Y = 523{,}38\ kg\ .$$

The resistance that the engine must overcome being known, let us see what happens inside the engine.

We will assume the motion has become uniform, which occurs shortly after it starts moving.

Let:

D (meters) The diameter of the driving wheel,

d (meters) The diameter of the cylinder in which the piston moves,

l (meters) The stroke of the piston.

Let, for a moment, z be the force acting on the piston or at the end of the crank. The circumference described by the end of the crank or the point of application of the force z is evidently 2l; the radius of this crank or the lever arm at the end of which the force z acts is therefore $\frac{l}{\pi}$.

The horizontal force opposing the motion of the engine can be considered as applied to the rail, in its direction, and at the point where it touches the wheel. If there were no friction, the wheel would spin on itself. But there is here a kind of gearing, a resistance produced by the asperities of the contact surface which is equal to the horizontal force, to the force Y that the engine must overcome.

This force Y acts with a lever arm of $\frac{D}{2}$.

For uniformity of motion, there must be an equilibrium between these two forces z and Y, or that their moments about the axis of rotation be equal; we therefore have,

$$Y\frac{D}{2}=z\frac{l}{\Pi}$$

hence $$z=\frac{\Pi D}{2l}Y\ .$$

Let us now call R the actual pressure expressed in Kilograms per square meter exerted by the steam on the piston.

The effective pressure will be $R-p-p'v$, where $p+p'v$ expresses the pressure, also in kg per square meter, experienced by the piston in the opposite direction to its motion.

p = 10335 kg, is the atmospheric pressure.

$p'v$ is the pressure due to the steam escaping through the blast pipe and which varies with the running speed of the engine; this pressure is due to the fact that the steam does not discharge into the open air, but into a duct called the blast pipe where its function, by exiting with a certain pressure, is to create a draft in the chimney pipe and thus favor combustion.

p' = 76.62 kg. We will assume it constant for simplicity, but new experiments might perhaps be needed here to determine the back-pressure experienced by the piston in its motion, due to the effect of the blast pipe.

Now, as there are two pistons, whose total area is $2\frac{\Pi d^2}{4}$, or $\frac{\Pi d^2}{2}$, we will have

$$Z=\frac{\Pi d^2}{2}(R-p-p'v)$$

or, replacing Z by its value as a function of y from $Z=\frac{\Pi d^2}{2l}y$, and extracting the value of R

$$[3]\qquad R=\frac{D}{d^2 l}Y+p+p'v$$

Applying this formula to the particular case we have already considered, and assuming, as for our engines on the Corbeil line,

$$D=1{,}33 \qquad d=0{,}33 \qquad l=0{,}457\ ,$$

we have, by performing the calculation,

$$R = 32542 \text{ kg}$$

Additional Notes. The weight of a 6-wheeled passenger locomotive used on the Corbeil line is 15 t; the adhesive weight, or weight carried by the two driving wheels, is 7 to 8 tons; the different parts of the engine have the following dimensions:

D diameter of the driving wheel . . . . . 1.85 m

l stroke of the piston . . . . . 0.457 m

d diameter of the cylinder . . . . . 0.33 m

Total heating surface is 69.50 m², of which 5.10 m² is for the firebox walls and the remainder for the tubes.

The weight of a 6-wheeled passenger locomotive (new model) to be used on the Orléans line is 16 t. The adhesive weight, or weight carried by the 2 driving wheels, is 7.5 t to 8.5 t.

$$D = 1.67 \qquad l = 0.508 \qquad d = 0.355$$

Total heating surface is 76.00, of which 2.87 is for the firebox walls and the remainder for the tubes.

The weight of a 6-wheeled goods locomotive (latest model) with coupled wheels to be used on the Orléans line is 16 t. The adhesive weight, or weight carried by the 4 driving wheels, is 10 to 11 t.

$$D = 1.37 \qquad l = 0.508 \qquad d = 0.355$$

Total heating surface is 76.00 m², of which 2.87 m² is for the firebox walls and the remainder for the tubes.

Tenders have 6 wheels; an empty tender weighs . . . . . 5,400 kg

full, with about 4 m³ of water and 500 to 600 kg of coke . . . . 10,000 kg

	Exact weights	
	Wagons empty (kg)	Wagons loaded (kg)
1st class carriages or diligences, carrying passengers	3345	5025
2nd class passenger carriages, carrying 30 people	3560	5660
3rd class open passenger carriages, carrying 30 people	2880	5400

Baggage wagons	4200	5200
Wagons for flour sacks	5060	6060
Wagons for merchandise	2955	5955
Post-chaise wagons	2795	5295
Stable-wagons	3120	4320

Weight of carriages and wagons.

In practice, one can assume, on average, that

a passenger wagon weighs empty . . . . . 3500 kg and full . . . . 5500 kg.

and a goods wagon weighs empty . . . . 3000 kg and full . . . . . 6000 kg.

Post-chaise wagons and stable-wagons are treated like passenger wagons.

The wheels of carriages or wagons running at high speed, i.e., with passenger trains, have a diameter of 1.00 m. The pair with its axle weighs 476 kg.

The rims of these wheels are all slightly conical; they have on the inside a flange or bead, projecting 3 to 4 centimeters, which prevents them from leaving the track.

The width of passenger carriages varies from 2.40 m to 2.50 m; with the footboards, this width is 3.10 m; a gate that would need to allow a carriage to pass should be at least 3.16 m wide.

The height of a stable-wagon above the ground is 3.40 m; this is the tallest wagon.

2nd Lesson.

In the last lesson we established the following formulas:

$$X = KM \pm gM + uv^{2.}$$
$$Y = F + (1 + \delta)$$
$$R = \frac{D}{d^2 l} Y + p + p'v$$

X representing the resistance to be overcome excluding the friction of the engine.

Y the horizontal effort, or total resistance to be overcome to pull the train and overcome the friction of the engine, or in other words, the resistance offered by the rail to the driving wheel in its motion.

R the actual pressure expressed in Kilograms per square meter that the steam exerts on the piston: the effective pressure will be $R - p - p'v$, $p + p'v$ also expressing the pressure in kg per square meter experienced by the piston in the opposite direction to its motion:

p is the atmospheric pressure, or 10335 kg per square meter.

$p'v$ is the pressure due to the steam on the other side of the piston, this term varies with the running speed. We will give p' the constant value 76.62 kg. The limits between which the speed varies are close enough for this hypothesis to be admissible.

The first of the formulas contains, in the term relating to the effort produced by gravity, the quantity M; in reality, it would be the component of the weight M normal to the inclined plane that should be used in the formula, but given the slight inclination of the track, the weight M itself is taken for its component.

Two particular features distinguish the locomotive from ordinary steam engines:

It was first a matter of producing a large quantity of steam in a short time; this was achieved by having a large number of small tubes pass through the boiler, through which the flame passes and which present a very large heating surface.

The steam, after acting on the piston and bringing it to the end of its stroke, escapes through a very narrow pipe which leads into the chimney: the draft, and consequently the intensity of the fire, are greatly increased by this arrangement.

According to what we have just said, the interior of a locomotive is divided into three main compartments: (fig. 1).

The firebox, the boiler and tubes, and the smoke box.

Let S be the effective steam generation expressed in cubic meters per hour; this quantity is measured by the amount of water used, or taken from the tender, minus losses occurring

either through the pump pipes, or through steam escaping via the safety valves, or finally through water passing into the cylinders in a liquid state carried along by the steam, which produces no effect. (We will not go into the detail of evaluating these losses; we will assume S is given by the result of an experiment on the engine.)

S varies with the speed of the train, but by a small amount: if S is, for example, the steam generation at a speed of 32 Kilometers and S' the steam generation at a speed of 40 Kilometers, we will have $S' = S \sqrt[4]{\frac{40}{32}}$.

Let μ be the relative volume of steam in the cylinder, i.e., the ratio, under a certain state of pressure and temperature, between the volume of the steam and that of the generating water which gave rise to it, or in other words, the number of cubic meters that the steam supplied by one cubic meter of water would occupy, or finally $\frac{1}{d}$, d being the density of this steam. Pambour establishes that μ and R are linked by the relation

$$[4] \qquad \mu = \frac{1}{n} + g_n R, \quad n = 0{,}0001421, \quad (q) \quad g = 0{,}0000000471$$

He also establishes, as an experimental fact, that the steam always remains, in the different states of temperature and pressure it may successively occupy in the engine, at its maximum density; we will accept this law without having had the opportunity to verify its accuracy; μS will be the volume of steam supplied in one hour by the boiler under the pressure R. This volume of steam has, during this time, constantly filled the cylinders.

The base area of the cylinders is $\frac{\pi d^2}{4}$.

The stroke of the piston is l.

The clearance of the cylinder being represented by c, the volume of the two cylinders will be

$$\frac{\pi d^2}{2}(l + c).$$

It is assumed that $$c = \frac{1}{20} l.$$

$\frac{\mu S}{\frac{\pi d^2}{2}(l + c)}$ will evidently be the number of times the cylinders have been filled in one hour: now, each time the cylinders are filled, the driving wheel turns through a half-circumference and consequently advances by $\frac{\pi D}{2}$; therefore, the distance traveled in one hour is

$$\frac{\pi D}{2} \; x \; \frac{\mu d}{\frac{\pi d^2}{2}(l + c)} \text{ meters}$$

this is the speed per hour expressed in meters, and the speed V which must be expressed in Kilometers will be

$$[5] \qquad V = \frac{1}{1000} \frac{\mu S D}{d^2 (l + c)}$$

this formula, together with the four preceding ones, serves to solve the two problems most often proposed: either to find the speed a train composed of a known number of wagons or a determined load will take, i.e., v as a function of M; or to determine the number of wagons the engine can haul at a given speed, i.e., M as a function of V.

By eliminating X, Y, μ and R between the five equations established previously, one arrives at the formula given by Pambour.

$$V = \frac{1}{1000} \frac{l}{l + c} \frac{1}{q} \frac{S}{(1 + \delta)\,[(K \pm g)\,M \pm gm + uv^2] + F + \frac{d^2 l}{D} (\frac{n}{q} + p + p' + p'v)}.$$

this formula gives V; but as a function of V and it is only by trial and error that one manages to use it; but it seems simpler to us to use the five formulas we presented above, and this is what we will do in all our calculations.

By solving the formula with respect to M, we find

$$M = \frac{1}{(1 + \delta)\,(K \pm g)} \left[\frac{1}{1000} \frac{l}{l + c} \frac{S}{q\,v} - \frac{d^2 l}{D} \left(\frac{n}{q} + p + p'v \right) - F \right] - \frac{1}{K \pm g} (u\,v^2 \pm g\,m)$$

M is still given here as a function of M because the term u v² implicitly contains M, since to determine v, a hypothesis on M is necessary because air resistance depends on the number of carriages.

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Discussion of the Formulas.

1° In these formulas, Y, as we have said, is the horizontal effort of the driving wheel on the rail. Now, the rail must produce a resistance at least equal to Y: because if Y were greater than this resistance, the wheel would spin on itself without advancing, or as they say, it would slip. This adhesion of the rail to the wheel, or friction, is about $\frac{1}{10}$ of the weight bearing on the driving wheel: it is to increase this adhesion that the part of the engine's weight supported by this wheel is increased; thus, for an engine of 16 tons, the driving wheels support 8 or 9 tons; therefore Y must not exceed 800 or 900 kg.

2° The value of R must not exceed 5 atmospheres; this is a regulatory measure guaranteed by the safety valves. We will therefore assume that R must never exceed 5 atmospheres, or in round numbers 50,000 kg.

3° μ decreases when R increases, and increases when R decreases, as proved by the relation $\mu = \frac{1}{n + qR}$. The smallest value of μ corresponds to the largest value of R; now, this largest value of R being 50,000 kg, the smallest value of μ will be 400. The corresponding temperature is 157.8°C. Therefore, the smallest value of v for a determined value of S will be

$$V = \frac{S\ D\ \mu}{d^2\ (l + c)\ 1000} = \frac{S\ D}{d^2\ (l + c)}\ \frac{400}{1\,000} = \frac{2}{5}\ \frac{S\ D}{d^2\ (l + c)}$$

if we apply this to the Corbeil engines for which $S = 2\ m^3$, we will have

$$\frac{D}{d^2\ (l + c)} = \frac{1{,}83}{0{,}0525} = \frac{18\,300}{525} = 35 \text{ approximately}$$

the minimum of v will be about 28 km. This is the minimum of v for $S = 2\ m^3$. If one wanted to go slower, vaporization would have to be reduced, but there would be no advantage in terms of fuel economy.

4° The maximum of v corresponds, as we have seen, to the maximum of μ and the minimum of R, which is understandable: now, R must always be strong enough for the engine to overcome its own friction and pull its tender. The maximum of v will therefore correspond to M = 10 T, i.e., the case where the train is reduced to the engine and tender.

Here it is necessary to consider the variation that S may undergo when the speed increases.

Let S' be the vaporization corresponding to this maximum speed, we will have:

$$S' = S \sqrt[4]{\frac{v}{32}}$$

S being the vaporization corresponding to v = 32 km. Let us make the hypothesis of v = 64 km, or 16 leagues per hour, $S = 2\ m^3$.

we will have:

$$S' = S \sqrt[4]{2} = 2^{m.\,c.}{,}38$$

Starting from this value of S' one would arrive, by applying our formulas, at a value of V which would be 59 Kilometers. This value is lower than the 64 km we started from; our hypothesis of V = 64 is therefore too high, we would need to set V = 60, one would find that this hypothesis is too low and that ultimately the value of V is between 60 and 64; by trial and error we would find V = 61 km for the maximum speed of the Corbeil engines. This is roughly what experiment has provided.

5° One could propose to find the value of M corresponding to the minimum of V, or V = 28 km. μ being equal to 400 and R to 50,000 kg.

Assuming $K = 3$ for reasons we will give shortly, we find $M = 200_T$, the weight of the tender being 10 t, the remaining weight for the wagons is 190 t, or dividing by 5.5 t which is the weight of a wagon, we find about 35 wagons. Now, in practice one should never go that far:

1. because the pressure in the boiler cannot be constantly maintained at 50,000 kg, given the large loss that would occur through the safety valves, this figure must be reduced a little.
2. because the pressure in the cylinders, or on the piston, must be a certain amount, however small it is assumed, smaller than the pressure in the boiler.
3. because, to start at stations, there must always be a fairly significant excess of force to set the train in motion, this train not being able, at the moment of departure, to fulfill the function of a flywheel as when it is in full motion.
4. because one is never perfectly on level ground, and, irrespective of losses resulting from the adopted layout, there are gradients resulting from irregularities in the laying of the rails and from unequal settling occurring in the track.
5. because there are curves which add much friction.
6. because the air is not always calm as we assume in our formulas, and it considerably increases resistance when it is directly contrary to the motion, or when it blows from the side and pushes the flanges of all the wheels against one rail, producing a kind of braking very detrimental to the train's motion.
7. because the state of the rails—dry, damp, greasy as during thaws—can vary the coefficient K. It is to account for this variation and place ourselves in an unfavorable hypothesis that we used $K = 3$ earlier instead of $K = 2.70$, the value given by Mr. Pambour.
8. because this state of the rails especially influences the adhesion of the engine and can reduce it considerably; the worst state of the rails is when they are greasy; the most favorable state is when they are very dry in summer, or washed by heavy rains.
9. because, finally, the engine may not be in good enough condition, or the engineer careful enough, to have the engine produce all the steam it can supply.

All these circumstances mean that, ultimately, formulas cannot completely replace experience and one must often still rely on it; however, formulas have the great advantage: 1° of giving a clear idea of the manner in which the motion takes place. 2° of allowing the establishment of the laws according to which the motion must vary. 3° finally, of not deviating greatly from the truth.

On Useful Effect.

We found above the value of M as a function of v. We will obtain the expression of the useful effect by multiplying this value of M by v, and we will have:

$$M\ v = \frac{1}{(1+\delta)(K \pm g)}\left[\frac{1}{1000} + \frac{l}{l+c}\ x\ \frac{3}{q} - d^2\frac{lv}{D}\left(\frac{n}{q} + p + p'v\right) - F_y\right] - \frac{v}{K \pm g}\left(uv^2 \pm gm\right)$$

but in practice it is better to find M and v separately and deduce Mv by numerical multiplication.

Estimation of useful effect in horsepower. A vigorous horse walking at a pace or at a rate of 4000 meters per hour, or 67 meters per minute (its most advantageous speed), can permanently exert an effort of 67 Kilograms, or, if you will, lift a weight of 67 kg suspended from the end of a rope, or in round numbers, raise 4,500 kg to one meter per minute. The force per hour will therefore be $4{,}500 \times 60 = 270{,}000\ kg\ .\ meters$. Now, as on a level railway an effort of 2.70 kg is needed to pull one ton, it follows that a horse will pull per hour as many times one ton over one kilometer as 2.70 x 1000 or 2700 is contained in 270,000, i.e., 100 tons. The force of one horse on a level railway is therefore represented by 100 tons pulled 1 Kilometer, or by 100, the unit being the ton multiplied by the kilometer.

To obtain the useful effort in horsepower, it will suffice to divide Mv by 100.

3rd Lesson

On Maximum Useful Effect.

If we retake the expression for Mv, we will recognize that v enters only in the negative terms, apart from the case of a descending gradient where Mv can acquire a very large, indefinite value, but which is due to the action of gravity and not to the power of the engine and consequently is outside our examination. Therefore Mv reaches its maximum when v is as small as possible for a determined vaporization. The minimum of v corresponds to the minimum of μ and the maximum of R, which is, as we know, $R = 50{,}000\ kg$.

Fuel economy is an important question. N being the quantity of coke expressed in kg burned per hour, a result given by experiment, the quantity of coke consumed per ton and per kilometer is , $\frac{N}{(M - c)v}$ c being the weight of the tender, which should not be counted in the useful effect produced by the coke.

The quantity of water S turned into steam per hour and acting in the cylinder is only a part of the total water S' expended per hour, and in general $S = 0.70\ S'$ considering losses of all kinds. $0.25\ S'$ is carried in a liquid state into the cylinder and $0.05\ S'$ is steam lost through the valves. The quantity of water consumed per ton and per kilometer is $\frac{S}{(M - c)v}$.

N varies per cubic meter of water between 140 and 175 kg. The journey from Paris to Corbeil therefore consumes 2 m³ of water, and about 350 kg of coke.

By means of the formulas established above, a host of problems can be solved, all very simple. We will cite a few:

Let M be the weight of a train on an ascending or descending gradient, and M'' the weight of a train on level ground that would produce the same resistance on the engine; what is the relation linking these two quantities?

Ascending gradient: $K\ M'' = K\ M + gM + gm$

Descending gradient: $K\ M'' = K\ M - gM - gm = K\ M - g\ (M + m)$

Consequently, for $K\ M = g\ (M + m)$, or $g = \frac{K\ M}{M + m}$, we have $M'' = 0$; this is the case where the train descends without the engine exerting any effort; indeed, one can conceive that there is a gradient for which the weight compensates for friction. When g is smaller than , $\frac{K\ M}{M + m}$ the engine must pull; when g is greater than $\frac{K\ M}{M + m}$, the engine will tend to be pushed; but it does not follow from this that the engine must cease to function, because it could be pushed so weakly that it would not have the required speed, and then the engine would need to act.

1. One can divide gradients into three classes:

1° Gradients between 0 millimeters and 3 mm, on which gravity is less than friction, and where the train would not move without the help of the engine.

2° Gradients between 3 mm and 5 mm, on which gravity overcomes friction, and where trains consequently descend by themselves, but with a speed that is not high enough to do without the help of the engine.

3° Gradients above 5 mm where gravity so greatly overcomes friction that trains would acquire too much speed during their descent, if their speed were not slowed by the action of brakes.

In the first case, the engine must act, and its action is calculated by the formulas above.

In the second case, the engine must still act, but moderately, i.e., by reducing vaporization, or wasting steam.

In the third case, the engineer must completely close his regulator, and the engine should no longer act. In this last case, it is a simple problem of gravity, in which the engine features only as a carriage heavier than the others.

The weight of the train is $M+m$; the force due to gravity $g(M+m)$; the resistance due to friction $K(M+m)$; the force acting on the train is therefore:

$$(g-K)(M+m)$$

Air resistance is $u\,v^2$.

The motion will accelerate first, and soon become uniform when we have

$$(g - K)(M + m) = u\,v^2$$

One can recognize, by applying this formula, that on an inclined plane of 10 millimeters per meter, for a train of 10 wagons, the speed will never exceed 20 leagues per hour, which is a speed often allowed on certain English railways.

Indeed: $M = 10 \times 5^t, 5 + 10 = 65$ $m = 15^t$; $M + m = 80^t$

$g - K = 10 - 3 = 7$ $u = 0.005064 \times (6 + 12) = 0.091$

We thus have, to find v, the equation: $7 \times 80 = 560 = 0.091\,v^2$

hence $$v^2 = \frac{560}{0.091} = \frac{560000}{91} = 6152$$

V is therefore a little below 79 kilometers, and this speed can still be reduced by curves and by irregularities in the track.

However, for greater safety and for the preservation of the rolling stock, the rule generally imposed on descending gradients is not to exceed a speed of 10 leagues or 40 Kilometers per hour, which is easily achieved with brakes. In England, they have even managed to sufficiently moderate speed with the help of brakes on gradients of 30 millimeters; but if all the brakes

were to break, which is a very unlikely case, the speed would not become infinite, as the public sometimes imagines, and it would be limited by air resistance.

Let us now propose to find the travel time on a railway in general, composed, like all railways, of a series of level sections, descents, and ascents.

Let:

L, L', L'', L''', be the lengths of each of these descents, ascents or level sections, expressed in Kilometers.

v, v', v'', v''', the corresponding speeds for a given train M, calculated according to the formulas above.

The travel time will be evidently:

$$\frac{L}{v} + \frac{L'}{v'} + \frac{L''}{v''} + \frac{L'''}{v'''} + etc.$$

and the average speed on the railway will be the length of the railway divided by the travel time, or:

$$\frac{L + L' + L'' + L''' + etc.}{\frac{L}{v} + \frac{L'}{v'} + \frac{L''}{v''} + \frac{L'''}{v'''} + etc.}$$

By applying this formula, one can recognize that there is always an advantage to being on level ground and that a level railway is better than a descent and an ascent succeeding one another.

Let us now find the average load of engines during their journey on a railway.

A train being formed, one can conceive that the load varies for each descent or ascent due to the effect of gravity.

Let M', M'', M''', M'''' be the loads which, for a given train, correspond to each descent, level section, or ascent.

The time during which each load is applied to the engine is

$$\frac{L'}{v'}, \frac{L''}{v''}, \frac{L'''}{v'''}, \ldots$$

and the average load is evidently:

$$\frac{\frac{M'L'}{v'} + \frac{M''L''}{v''} + \frac{M'''L'''}{v'''} + \ldots}{\frac{L'}{v'} + \frac{L''}{v''} + \frac{L'''}{v'''} + \ldots}$$

If the journey in question consists of descents and ascents placed between two level points, it will always be found that the average load of the engine on these slopes will be higher than it would be on a level plane.

When finalizing a layout, all these questions must be examined to determine which one should be preferred; it is understandable that the problem varies for a passenger railway and a goods railway. In the first case, speed is a very important element; for the second, on the contrary, it is the load that must be considered above all.

On the means of climbing ascents on railways.

On an ascent below 5 millimeters per meter, arrangements are generally made to reduce the train enough to be able to climb it without inconvenience, with no other help than a slightly higher pressure in the boiler.

On an ascent between 5 and 10 millimeters, one must count at least sometimes on a helper engine, and as far as possible, there should be a station near such an ascent where relief and helper engines are stationed.

On an ascent greater than 10 millimeters, stationary engines must be used.

All these means have drawbacks that are easy to imagine.

We will now speak of the probable future of locomotives and the modifications and improvements they have already received and will probably still receive.

We will first recall the formulas linking pressure and temperature for water vapor at its maximum density.

Pressure p will be expressed in Kilograms per square centimeter.

The temperature t in degrees centigrade.

This stated, we have:

1° for pressures less than the atmosphere, below 1.0335 kg per square centimeter:

$$\left\{\begin{array}{ll} \text{Formula of southern} & p = 0{,}0034542 + \left(\dfrac{46{,}278 + t}{145{,}360}\right)^{5{,}13} \\ \text{and} & t = 145{,}360\ \sqrt[5{,}13]{p - 0{,}0034542} - 46{,}278 \end{array}\right\} \quad (1)$$

2° For pressures between 1 and 4 atmospheres, or between 1.0335 kg and 4.1440 kg per square centimeter:

$$\left\{\begin{array}{ll} \text{Formula of Pambour} & p = \left(\dfrac{72{,}67 + t}{171{,}72}\right)^{6} \\ \text{and} & t = 171{,}72\ \sqrt[6]{p} - 72{,}67 \end{array}\right\} \quad (2)$$

3° For pressures between 4 and 50 atmospheres, or between 4.1440 kg and 51.6750 kg per square centimeter:

$$\left\{\begin{array}{cc} \text{Formule of Dulong and Arago} & p = \left(0{,}28658 + 0{,}0072003\ t\right)^5 \\ \text{and} & t = 138{,}883\ \sqrt[5]{p} - 39{,}802 \end{array}\right\} \quad (3)$$

Let us now call μ the relative volume of steam taken in a certain state, i.e., under a certain pressure and at a determined temperature, $\mu = \frac{1}{d}$, d being the density of the steam, that of water being taken as unity.

μ expresses the ratio of the volume occupied by the steam in the state considered to the volume of water that gave rise to it.

μ also expresses the number of cubic meters that one cubic meter of water, turned into steam at the temperature and under the pressure considered, would occupy.

Thus for steam at 100°C under atmospheric pressure, it is known that the density is $\frac{1}{1700}$; that of water at its maximum density being taken as unity; therefore $\mu = 1700$, so one cubic meter of water at this temperature of 100°C and under atmospheric pressure $p = 1.0335\ k$ will occupy a volume of 1700 cubic meters.

This stated, we have:

According to Mariotte's law for two vapors whose temperatures, pressure and relative volume are represented by t, p and μ for one and by t', p' and μ' for the other,

when $t = t'$ $$\frac{\mu}{\mu'} = \frac{p'}{p} \quad \ldots\ldots\ldots\ldots (4)$$

and according to Gay-Lussac's law, we have:

when $p = p'$ $$\frac{\mu}{\mu'} = \frac{1 + 0.00364\ t}{1 + 0.00364\ t'} \quad \ldots\ldots\ldots (5)$$

By combining these two formulas (4) and (5), knowing the relative volume μ' of steam under a certain pressure p' and at a certain temperature t', one can calculate the relative volume μ of the same steam under a pressure p and at a temperature t.

Indeed, let μ'' be, for a moment, the relative volume of the same steam at pressure p and temperature t'. We will have, by virtue of relation (5):

$$\frac{\mu}{\mu''} = \frac{1 + 0.00364\ t}{1 + 0.00364\ t'}$$

and due to the formula (4)

$$\frac{\mu''}{\mu'} = \frac{p'}{p} \qquad \text{hence} \qquad \mu'' = \mu' \cdot \frac{p'}{p}$$

and $$\mu = \mu'' \; x \; \frac{1 + 0.00364\ t}{1 + 0.00364\ t'}$$

or $$\mu = \mu' \; \frac{p'}{p} \; x \; \frac{1 + 0{,}00364\ t}{1 + 0{,}00364\ t'} \quad \ldots\ldots\ldots (6)$$

Now, if we do without this value of μ

$$p' = 1.335\ kg \qquad t' = 100° \qquad \mu' = 1700\ ,$$

and then substitute in place of p and t the values corresponding to the different states of the steam always remaining at its maximum density, values of p and t which are given to us by formulas (1), (2) and (3), we will find the corresponding values of μ.

We will thus have, to calculate the different values of μ for steam at its maximum density, the formula:

$$\mu = 1700 \; x \; \frac{1.0335}{p} \; x \; \frac{1 + 0.00364\ t}{1.364} = 1287 \; \frac{1 + 0.00364\ t}{\mu} \quad \ldots\ldots (7)$$

by substituting for t and p the values deduced from formulas (1), (2) and (3).

The values of μ calculated according to this formula are entered in the third column of the table below.

Now Pambour gave, for the direct relation between μ and p (the only quantities it is essential to know), the formula:

$$\mu = \frac{1}{n + q\ R} \qquad R = 10\,000\ p \qquad n = \frac{1421000}{(10)^{10}} \qquad q = \frac{471}{(10)^{10}}$$

or $$R = \frac{(10)^{10}}{471\ \mu} - 9017 \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

It is according to this formula (8) that the values of μ given in the fourth column of the table below were calculated.

This formula is not applicable in the case where R is < than 15,000 kg, but this is a case that does not concern us.

R being the pressure in Kilograms per square meter, and p the same pressure per square centimeter, we evidently have

$$R = 10{,}000\ p\ .$$

By means of the above formulas, the following table can easily be formed:

Values of p in Kilograms per square meter	Temperature in degrees centigrade	Values of μ calculated by the formula (7)	Values of μ calculated by the formula (8)
1 000	45°.9	15 019	
2 000	59°.6	7 831	
3 000	68°.4	5 356	
4 000	75°.1	4 097	The formula (8) given by Pambour is not applicable for a pressure below 1500K. It should be modified (see Pambour)
5 000	80°.5	3 329	
6 000	85°.2	2 810	
7 000	89°.2	2 435	
8 000	92°.8	2 152	
9 000	94°.4	1 921	
10 000	99°.0	1 751	
11 000	101°.8	1 604	
12 000	104°.4	1 480	
13 000	106°.7	1 375	
14 000	109°.0	1 284	
15 000	111°.1	1 205	1 178
16 000	113°.0	1 135	1 116
17 000	114°.9	1 074	1 060
18 000	116°.7	1 019	1 010
19 000	118°.4	969	964
20 000	120°.1	925	922
21 000	121°.7	884	884
22 000	123°.2	847	848
23 000	124°.6	813	816
24 000	126°.1	782	785
25 000	127°.4	754	757
26 000	128°.7	727	731
27 000	130°.0	702	707
28 000	131°.2	679	684
29 000	132°.4	658	663
30 000	133°.6	638	643
31 000	134°.7	619	624
32 000	135°.8	601	606
33 000	136°.9	584	589
34 000	137°.9	569	579
35 000	138°.9	554	558
36 000	139°.9	540	544
37 000	140°.9	526	530
38 000	141°.8	514	517
39 000	142°.8	502	505
40 000	143°.7	490	493
"			
"			

Values of p in Kilograms per square meter	Temperature in degrees centigrade	Values of μ calculated by the formula (7)	Values of μ calculated by the formula (8)
41 000	144°.6	479	482
42 000	145°.3	468	471
43 000	146°.1	459	461
44 000	147°.0	449	451
45 000	147°.8	440	442
46 000	148°.7	431	433
47 000	149°.5	423	424
48 000	150°.3	415	416
49 000	151°.1	407	408
50 000	151°.8	400	400
51 000	152°.6	393	393
52 000	153°.3	386	386
53 000	154°.1	379	379
54 000	154°.8	373	372
55 000	155°.5	366	366
56 000	156°.2	360	360
57 000	156°.9	355	354
58 000	157°.6	349	348
59 000	158°.3	344	342
60 000	158°.9	339	337
61 000	159°.6	334	332
62 000	160°.3	329	327
63 000	160°.9	324	322
64 000	161°.5	319	317
65 000	162°.1	315	312
66 000	162°.8	311	308
67 000	163°.4	306	303
68 000	164°.0	302	299
69 000	164°.6	298	295
70 000	165°.2	294	291
71 000	165°.7	290	287
72 000	166°.3	287	283
73 000	166°.9	283	279
74 000	167°.5	280	276
75 000	168°.0	277	272
76 000	168°.6	273	269
77 000	169°.1	270	265
78 000	169°.7	267	262
79 000	170°.2	264	259
80 000	170°.7	261	256
85 000	173°.3	247	241
90 000	175°.7	234	228

"				95 000	178°.1	223	216
"				100 000	180°.3	213	206

It is also useful to recall here what latent heat is, or the heat absorbed when water passes from the liquid to the gaseous state.

Calling a calorie the quantity of heat necessary to raise the temperature of one Kilogram of water by one degree centigrade, it will be remembered that to pass one Kilogram of water from the liquid to the gaseous state, there is a quantity of 550 calories which is absorbed, which does not manifest itself on the thermometer and which, in a word, constitutes latent heat.

One can understand from this, and the table we have just given proves it, why not much more heat is needed to raise steam to a high pressure than to a medium pressure or even to a low pressure. It must also be considered that the total pressure in locomotives must always be reduced by the atmospheric pressure, i.e., by 10,000 kg/m², to obtain the effective pressure of the engine; and that this constant reduction, whatever the pressure, is all the more significant the lower the pressure.

Thus: if one wants to have an effective pressure of 20,000 kg/m² in the engine, a total pressure of 30,000 kg/m² will be needed, and consequently a temperature which, according to our table, is 133°C; for an effective pressure double the first, or 40,000 kg/m², a total pressure of 50,000 kg/m² and a temperature of 151°C will be needed, i.e., per Kilogram of water evaporated, 133 + 550 calories = 683 calories for the first case, and for the second case 151 + 550 calories = 701 calories.

One can therefore understand why and how important it is to use steam at a high pressure; but since, according to the theory we have just developed, the pressure taken by the steam in the cylinder depends on the load the engine is called upon to pull, one will often be forced, despite oneself with current engines, to use steam only at a low pressure, and there will be a real loss of force or fuel.

Thus: on the Corbeil line we saw in our first lecture that, according to our formulas, the pressure is 32,542 kg for a train of 10 carriages, and for a smaller train it is below three atmospheres.

The invention of fixed-expansion engines, which are beginning to be used in England, Belgium, and France, largely remedies this drawback: the steam can then act with a more considerable pressure. In engines built according to this system, the piston stroke under the direct effect of steam is $\frac{65}{100^e}$ or $\frac{75}{100}$ of the total stroke, the movement being completed by the effect of expansion; but these engines in turn have the drawback of not being able to pull loads as heavy as the first ones, assuming that in both types the maximum pressure of 50,000 kg is never exceeded.

The drawback we have noted is, moreover, not entirely eliminated by this system, since one is forced to reduce the steam tension for light loads, and if, for example, on a railway there is an ascent of 5 mm to climb, one must arrange for the engine to be able to climb it with a total pressure of 50,000 kg and then resign oneself to running over the rest of the railway with a lower pressure. A variable-expansion engine would be the real solution to the problem, because it would allow the steam to always be used at 5 atmospheres; the mechanism would let steam onto the piston for only ⅘ ¾, ⅔ of the stroke when the ascents were gentler, thus increasing the expansion; as the ascent became gentler, it would adjust to always use its steam at 5 atmospheres. Engines of this type are currently being built in England by Mr. Stephenson; some have been manufactured in France by Mr. Meyer, which have been used on the Basel to Strasbourg line.

Finally, we will say a few words about the different fuels that can be used on railways.

The calorific power of a fuel is called the quantity of heat it is capable of developing.

A calorie is called the quantity of heat needed to raise one Kilogram of water by one degree centigrade.

One Kilogram of coke can develop 7000 calories.

. . . . . of coal . . . . . 6440 . . . . . .

. . . . . of charcoal . . . . . 6000 . . . . . .

. . . . . of air-dried wood . . 2945 . . . . . .

. . . . . of peat . . . . . 1500 . . . . . .

It is immediately apparent that peat does not give enough heat. Air-dried wood has been used on some German railways where it was very cheap; but besides the drawback of giving little heat, it produced sparks that could lead to accidents.

Charcoal is expensive and of little advantageous use.

Finally, coke is preferred to coal because it provides more heat and because coal produces an unpleasant odor and sulphurous gases which deteriorate the engine.

In all cases, the best fireboxes utilize only 0.50 to 0.60 of the heat developed.

According to the calorific power we have just given for coke, and taking half of it based on the previous observation, one would find that one kilogram of coke can vaporize 5.38 kg of water; between 5.6 and 7 Kilograms are obtained in engines; but it should be noted that the water consumed and measured in the tender is greater than the water vaporized, as previously stated.

All the details given above on locomotives are extracted from Mr. Pambour's work entitled Traité théorique et pratique des machines locomotives.

One can consult for details on the construction, maintenance, and operation of locomotives the work of Messrs. Flachat and Petiet entitled Guide du mécanicien conducteur de machines locomotives.

Description of the works of the Paris to Orléans Railway

The track is the specific part of a railway; it is nowadays arranged in a more or less uniform manner.

The track consists of two iron pieces called rails, laid and maintained on cast-iron supports, which are referred to indiscriminately by the names of chairs, blocks, supports, or seats. The chairs are fixed onto transverse wooden pieces spaced about 1 m apart and resting on the ground of the railway via a layer of sand or broken stone which prevents the sinking of the sleeper, when, due to the effect of humidity, the ground becomes soft and not very resistant; they also have the advantage of completely enveloping the sleeper, holding it in all directions and thus contributing to its preservation on the one hand and to its solidity on the other.

These layers are called ballast; their thickness is 0.45 m to 0.50 m. It is advantageous to form them with sand to seat the sleepers well. It is desirable that the sand is not too earthy, i.e., mixed with a large quantity of earth, because the sleepers would then be more or less as if placed simply on the ground and the ballast would not offer the sleeper the kind of solid foundation it is intended to provide. It is also not good for the sand to be perfectly pure, because in that state the grains have too much ease in rolling over each other and consequently the layer does not offer a solid and stable enough foundation.

When sand is too expensive, it is replaced with broken stones, but the sleepers are not as well placed on ballast constructed in this way as on sand. Broken stones have the sole advantage of giving a quick outflow to water; their drawback is, when there is settlement, not to lend themselves as well as sand to the raising of the sleeper.

The most important part of the track is the rail; its shape varies on each railway. The rail must have a sufficient running surface so that the wheel is not worn, and the width of this surface varies between 0.05 m and 0.06 m; for the Orléans railway, the average of 0.055 m was adopted. The rail must have a certain height so as not to bend between two supports under the load of the wheel. It is known that for this, the best form to give to the cross-section is that of a double T or a double mushroom. Except for some variations in dimensions, this form appears today to be generally adopted. However, on the Paris to Versailles railway (Left Bank), the form represented by figure (2) was adopted. It is easy to see that rails of the first form can be turned over in different ways, always offering the same running surface and the same base, whereas rails of the second form can only be used on one side; they also have the advantage of resting in the chair on a wide base, which contributes to a good seating.

Double T-shaped rails were used on the Paris to Versailles railway (Right Bank), but with a running surface of 0.06 m; the projection of the upper part over the middle part seemed to us a little too pronounced and likely to favor wear of the rail on its two edges; such is the reason why on the Orléans railway the surface was reduced to 0.055 m and the thickness in the middle increased.

The rail as it was formerly used generally presents a flat surface. Recently, a slight convexity has been given to it, the effect of which is to bring the pressure exerted by the wheel back to the center of the rail; this wears it out less quickly. Furthermore, the bright line that friction traces on the rail becomes more or less continuous, whereas on flat rails this line appears sometimes on one side, sometimes on the other. The running of the train appears to be smoother with the convexity.

The rise of the convexity is . . . . . 0.0014 m

The radius of the convex surface . . . . . 0.1647 m

The chord approximately . . . . . 0.045 m

The height of the rail (not including the two convexities) is 0.11 m.

The weight of rails has continually increased; we have arrived at 30 kg, this is the weight we adopted; it has already been exceeded in England; on the Rouen railway, it is 35 kg.

The price of the rail varies from 30 to 33 francs per 100 kg at the works; but transport to the sites greatly increases the price. For the Orléans railway, the iron was taken largely from Decazeville; it then comes via Bordeaux and Nantes. Some was also taken from Alais; it goes down the Rhône, goes around Spain to come to Nantes to take the Loire as far as Orléans. These long journeys bring the price per 100 kg to 39 and 40 francs. Finally, part of the rails was also taken from Le Creusot.

Rails are placed end to end: for this they must be cut squarely, the ends must be very clean of any burrs and dressed with a chisel and file; because the use of a hammer would alter the shape of the cross-section. Each portion must be cleared on both sides at a sufficient distance from the work-hardened ends so that the two extremities are perfectly sound.

It is important that the rails are well constructed before leaving the works; to avoid reworking them cold on the sites, which would give rise to very costly labor.

The length of a rail is 4.50 m. A tolerance of 0.04 m less is allowed for a small number placed in curves.

The iron must be of good quality; by this it is not meant that it should offer the same properties as that used in suspension bridges, for example; it obviously does not need great malleability, but it must be hard, compact, not brittle when cold, perfectly welded, without streaks or cracks, and as free from defects as possible.

Before being used, the rail is subjected to a test which consists of placing it on two supports 0.08 m wide, separated by an interval of 1.25 m, and loading it in the middle with a weight of 10,000 kg. It must not retain any alteration after the test.

The chairs are made of cast iron, first or second fusion; they are distinguished into joint chairs and intermediate chairs. The former have a width of 0.14 m and the latter 0.10 m.

Their weight is, for a joint chair . . . . . 12.80 kg

for an intermediate chair . . . . . 9.20 kg

The contact of the rail with the jaws or faces of the chair must occur exactly over the entire extent of the surface against which it is supposed to bear.

The cast iron must be soft and easily worked with a file, with a close and homogeneous grain, free from defects.

The surfaces must be clean; the edges trimmed, the sprues and seams filed down.

The price, for first fusion cast iron, varies including transport from 30 to 32 francs per 100 kg. A reduction would be obtained with second fusion cast iron, but perhaps less solidity and more chance of breakage.

The chairs are fixed to the sleepers by means of iron spikes, 0.14 m in length, not including the head, and 0.018 m in diameter. The head has a diameter of 0.024 m and a thickness of 0.0113 m. A spike weighs 27 to 30 grams.

The spikes must be made of best quality iron, soft and not brittle. The head must be upset from the solid and not welded on, because due to the shocks the sleepers have to undergo, it would easily come off. Good spikes should not break when tested by bending them through 45°. Price per 100 kg: 60 to 65 francs.

To hold the rail in the chair and establish a very intimate contact between the lateral surface of the rail and the jaw of the chair, a wooden wedge is driven with a sledgehammer into the space left for the introduction of the rail into the chair.

The wedges are made of oak wood, very dry, very sound, without sapwood.

Wedges for joint chairs have a length of . . . . . 0.30 m

for intermediate chairs . . . . . 0.25 m

They are manufactured by machine with great precision; a wedge is worth about 0.20 franc; it is slightly conical; it must bear over the entire length of the chair.

The sleepers are made of good quality oak, roughly squared. The use of softwood must be avoided as much as possible because it rots easily and does not hold the spike firmly enough. However, when in the locality where one is, oak is too expensive and fir wood, for example, is low in price, there may be reason to use the latter. In such circumstances, it would be important to know processes for giving the wood a certain hardness, and ensuring it a certain

durability. There are processes in England, in France; that of Boucherie appears to be very good but has not yet received large-scale applications.

A standard joint sleeper has:

Length 2.45 m; width 0.30 m and thickness 0.15 m, volume 0.11 m^3

A standard intermediate sleeper has:

Length 2.45 m; width 0.25 m and thickness 0.15 m, volume 0.09 m^3

Tolerances are allowed:

On length: 0.25 m more or less.

On width: 2 centimeters more and 7 centimeters less for intermediate sleepers, and for joint sleepers 10 cm more and nothing less.

On thickness: 2 cm more or less.

The total average volume of the entire supply must not be exceeded, so that the contractor cannot lead to an exaggerated volume.

The timber for the sleepers of the Orléans railway was delivered partly to the ports on the Seine between Paris and Corbeil and to the port on the Loire at Orléans at a price of 73 francs; 10 francs must be added for transport to the sites, cutting, and chair fitting per cubic meter, which comes to 83 francs per cubic meter; in Paris, a little more was paid for the Corbeil line.

The prices for chair fitting and other labor for laying tend to fall as workers are trained and become more practiced and skilled for the different tasks.

Chair fitting. — This operation is the basis of a good track: it must be done with care and precision.

The supports must be laid with a template, very exactly at the required distance and inclination, in the same line.

The surface on which the support rests must be perfectly sound, without sapwood, and well dressed so that the support bears over its entire base. The chairs are given an inclination of to $\frac{1}{20}$ bring the carriages back towards the center of the track. As far as possible, notches must be avoided and a well-cleared surface where water cannot stagnate must be provided.

The spikes must be driven with care. Their hole is drilled with an auger so that they fit tightly, but without too much force, so as not to split the wood. It is for this reason also that their sharp edge must be square to the grain of the wood.

Laying the track. Formerly, only 1.44 m width was given between the inner edges of the rails of the same track. This distance, equal to that of the wheel flanges, was no longer sufficient on curves, where this width had to be increased, and increased all the more as the radius of the curve was smaller. The drawback of having various templates and considerable friction was eliminated by adopting the uniform spacing of 1.45 m.

In track switches, it is important to reduce the tracks to the exact width of 1.44 m of the carriage flanges.

On curves, the outer rail, or the one with the larger radius, is raised to counteract and reduce the efforts of centrifugal force by the weight of the carriages.

The raising is:

10 mm for curves with a radius of 1,000 to 1,200 m.

8 mm . . . . . 1,500 m.

4 mm . . . . . 2,000 m.

3 mm . . . . . 3,000 m.

2 mm . . . . . 6,000 m.

Laying the sleepers. Sleepers must always be laid square to the axis of the track. Different systems have been followed for their spacing. On the Saint-Germain railway, they are spaced 1.125 m apart, thus offering three intermediate support points. In this arrangement, if the ends are not perfectly supported, they can bend and give rise to overhangs which manifest themselves during the passage of a train by the spurting of water or sand. On the Orléans railway, it was preferred to adopt, especially in poor ground, intermediate sleepers spaced 1 m apart, which gives only 0.75 m for the ends of a rail section. Economy alone led to the use, in cuttings, of 9 intermediate supports spaced 1.25 m apart, which gives 1 m for the end lengths. A small gap must be left for expansion between 2 successive sections. 9 mm are sufficient when working at a temperature of 10 to 15°C.

On curves, it is important to have shorter rails for the line on the concave side. They are made 2 or 3 centimeters shorter and interposed between the 4.50 m rails. — When curves have a small radius, the rails must be bent before laying; but with a radius of 1000 m and above, this is unnecessary; the wedges are sufficient to give them the slight flexure that suits them. To seat the sleepers, they must not be struck too hard in order to avoid pulling out the spikes; it is by packing sand underneath with English picks that the desired solidity is obtained. To ensure that a sleeper is properly packed, the rail is un-wedged and it is observed whether the sleeper, thus isolated, i.e., not held or supported by the rail, settles.

Ballast. Figures 3, 4, 5 and 6 show the profiles adopted in the case of ballast made of sand or broken stone, in the dual circumstance of cutting and embankment. The crowning of the surfaces between the iron tracks is not intended, which would be bad, to make water flow under the rails—the ballast is too permeable for that—but to have a small excess of materials forming a supply.

In maintenance, it is necessary to constantly lift and repair as soon as a deformation occurs, to avoid major repairs, which are always costly and dangerous for the rolling stock.

In order to preserve them, the sleepers and even the wedges must always be covered with sand.

When packing sand under the sleepers, care must be taken that they are firmly consolidated under the chairs and at both ends, and not in the middle.

Wedges must be driven carefully and without forcing, for fear of splitting or breaking the jaws of the chair.

Price per linear meter of track.

In the expenses incurred by the construction of an iron track, there is a more or less constant part that we will evaluate. This is the part relating to the laying of rails on suitably prepared ground.

Supply of materials.

Sleepers per linear meter have a volume of 0.10 m^3; estimating the price per cubic meter at 83 francs, including the costs of chair fitting, we find . . . . . 8.50 fr

60 kg of rails at 0.3886 fr per kg gives per linear meter . . . . . 23.30 fr

20.66 kg of cast iron for chairs at 0.30555 fr per kg . . . . . 6.30 fr

1.14 kg of spikes at 0.63110 fr per kg . . . . . 0.90 fr

2 wooden wedges . . . . . 0.42 fr

Which gives in total . . . . . 39.05 fr

for the supply of materials entering into 1 linear meter of track.

The prices given above are the average prices for the Orléans railway.

Labor. The transport of 200 kg of materials (necessary for the construction of 1 linear meter of track) from the ports of the Loire and the Seine to the depot sites on the line, over a reduced distance of about 10 km, cost, given the poor roads, ... 2.00 fr

Laying the track and transport by wagon from the depot sites to the points of use require . . . . . 1.65 fr

To complete these expenses, must be added for site rental, costs of receiving materials, work supervision, temporary laying, lifting of the track during the first months following laying and during temporary transport . . . . . 2.30 fr

General total . . . . . **45.00 fr**

Which per *kilometer* of double track . . . . . **90,000 fr**

Price of Ballast. The price of sand is very variable; it ranges from 2 to 8 francs and sometimes even to 10 francs.

Adopting an average of 5 francs for sand or broken stone, and assuming 4 m³ of these materials per linear meter, considering the liftings that become necessary in the early stages of traffic, we can take . . . . . 90 + 20 = 110 fr

for the price of one linear meter of double track.

But additionally, there are service tracks for sidings, for relief engine depots, for terminal stations, for workshops and engine sheds, for goods stations; estimating them at $\frac{1}{20}$ of the length, which per linear meter comes to . . . . . 6.00 fr

we find . . . . . 116.00 fr

for the price per linear meter of track.

In an estimate relating to the Northern railway, the figure of 125.00 fr is adopted.

Based on the experience of English railways, and considering the difference in prices for labor and raw materials that may exist in France and England, if one increases the weight of the rails, the strength of the chairs, the dimensions of the sleepers even slightly, one will easily reach this figure; it can be assumed that the price per linear meter of double track, with ballast, will come to 115 to 125 francs. One will hardly deviate from these limits except in exceptional circumstances.

5th Lesson

A remark to be made on the laying of the track is that the sleepers are extended about 0.75 m on each side and outside the track, which may, at first glance, seem superfluous; but this arrangement greatly contributes to the solidity of the railway, by extending the base on which the track rests. The thickness of the sleeper must be great enough for the spike to be completely embedded in the wood, and not protrude from the inner surface of the sleeper. The thickness of the sleeper must also be sufficient to resist bending; but the first of these conditions being fulfilled, the second is generally also met.

On any railway line, it must be required that trains going in one direction always keep to the same track, and that those going in the opposite direction run on the other track. However, it is always necessary to establish communications between the two tracks at intervals; these communications are also indispensable at both ends of the railway.

We will speak here of the different means used to establish these communications.

The turntable is used to move a locomotive or any carriage from one track to another that forms any angle with the first. This apparatus consists of a circular cast-iron plate on which rails are fixed by means of countersunk bolts. Sometimes these rails are integral with the plate, and are then made of cast iron, but this has a drawback: the plate is greatly compromised when the rails are broken.

This plate is supported at its center by a pivot on which it turns. (fig. 7).

Besides this pivot, there are rollers placed at a certain distance from the center and on which rests a kind of circular rail fixed underneath the plate; these rollers also turn on an also circular cast-iron track.

The rails of the plate being placed facing those of the track on which the carriage is, the latter is moved onto the plate, and the whole system is then turned until the carriage is opposite the track onto which it is to be moved. It then only remains to push it to make it leave the plate. It can be seen that for this maneuver, a single line of rails on the plate would suffice, but operations are shortened by placing two lines of rails at right angles. Indeed, if an entire train has to be switched, after operating on one carriage, there is no need to bring the plate back to its original position; the second rails are in the necessary position to receive the second carriage. It is clear that this only happens when the two tracks are at right angles.

When two systems of rails are used, they must be interrupted at the crossing to allow the passage of wheel flanges; a gap of 0.05 m is left.

Around the turntable there is a small circular wall. It was formerly made of stone; but the shocks occasioned by the sudden stopping of the plate, when the catch intended to hold it in the necessary position was closed, these shocks caused the stones to crack. It has been replaced by a small wall formed by a cylindrical cast-iron plate.

There are turntables for locomotives and others for wagons, diligences, etc. The former are larger.

They have a diameter of 4.20 m. The latter are only 3.40 m in diameter.

The cast-iron plate is not completely solid; it is hollowed out in the parts that do not support weight. These voids are covered by very thin cast-iron plates, or by flooring with sheet metal on top, or simply by planks. Cast iron or sheet metal are indispensable for turntables used for locomotives, because falling fire could burn the wood.

Turntables for locomotives, with their cross-bracing, their surrounding curb, their carriage, and the plate itself, containing 9,000 kg of cast iron and 700 kg of wrought iron, delivered and placed on site cost 6,000 to 6,500 francs; those for carriages require 4,000 to 5,000 kg of cast iron and cost 3,000 to 4,000 francs.

Turntables are necessary for loading post-chaises, horses, and in general everything that cannot be loaded from the side. Turntables are placed against a small wall high enough above the track for the post-chaises to arrive at the level of the trolley onto which they are loaded.

The turntable has drawbacks: if an entire train has to be moved from one track to another, the maneuver must be repeated a great many times and this takes a lot of time.

Therefore, recourse to another system had to be found, and the track switch was employed. It consists of a curved section of track *AB*, which goes from one to the other of the two tracks to be connected, so as to form a very acute angle with both. The radii of these curves are 400 or 500 m, and they are generally traversed at low speed.

It is necessary at points *A* and *B* to have an arrangement that allows the train to continue its route on the same track or to switch to the other track. This is achieved by means of movable points.

Here is the system generally employed. (fig. 8). The parts *EF* and *GH* of the rails are movable around centers *E* and *G*. When a train arrives at *B*, it will take the direction *BB′* or *BB″* depending on whether the points are in the position *EF*, *GH* or in the position *EF′, GH′*. Examining the figure suffices to understand this. To put the points in a suitable position, they can be fixed on a cross-piece moved by means of a crank.

There are detailed systems, some more convenient than others. They are always constructed according to the preceding principle; a counterweight placed at *P* on an inclined lever arm forces the points to remain in the position *EF*, *GH* on the main track, so that a train coming from *B* always takes the route *BB″*. If a train comes in the direction *B″B*, it finds the track correct, and if it comes following the direction *B′B*, it will force the points to open to let it pass, and after its passage the points will return to their position.

Thus the track is suitable and can be traversed either in the direction *BB″*, or *B″B*, or between *B′B*; the switchman is only necessary for going along the line *BB′*; and arrangements can be made so that travel in this direction is rare.

When two tracks cross, the rails must be arranged in a particular manner. In the attached figure (fig. 9), all the rails in black belong to one of the tracks and the others to the second. The parts *a a′ b b′* are what are called guard rails.

The guard rail *a a′* would prevent the right-hand wheel of a carriage going in the direction cd on the black track from entering the gap *e f*. When rails are thus very close together, they are fixed on the same chair.

On a long line, the distribution of these switches must be combined to serve everything and make them as rare as possible. On the Orléans railway, there is a switch approximately at each intermediate station, in order to establish communications at intervals between the inbound track and the outbound track. Regulations require that carriages going on the same track all go in the same direction. However, this is not always possible; it can be conceived, in fact, that if a train is forced to stop on track *AC* (fig. 10), and it calls to its aid a locomotive coming in the direction *DB*, the latter will be obliged first to continue beyond *B* to see at which point the distressed train is, and then to come back and change track at *B*; it will therefore follow track *DB* in reverse.

The engines that will serve the Orléans railway will only go as far as Étampes, and there will be a depot between Paris and Étampes; so that there will be engines every eight leagues.

These engine sheds consist of a shed *A* connected to the main line by means of a branch *AB* on which there is a turntable *C*. This turntable allows the locomotives to be arranged so as to go in either direction. There is also a hydraulic crane used to supply the engines. This hydraulic crane is simply a pipe in communication with a water reservoir and which brings water above the tender of the engine. It is worth noting on this subject that it is important always to have good quality water. There are waters which deposit a lot of calcareous salts which quickly deteriorate the engines.

At intermediate stations, it is necessary to have platforms, so that passengers can easily get into and out of the carriages. On some railways, these platforms have been made similar to those of main stations, i.e., one meter above the ground so as to be able to step directly from the platform into the carriage; but as these platforms are quite expensive to build, they are given only the length of a train. This arrangement wastes time because the driver, not being able to stop precisely at the moment when the train is in front of the platform, is obliged to arrive there by successive oscillations or to slow down the speed well before the station. On the Orléans railway, the platforms have been replaced by kinds of steps 0.25 to 0.30 m high, which, being cheaper to build, can be of greater length and seem to us sufficient for all passenger needs.

It is especially around and inside the terminal stations that it is important to arrange the tracks and switches well. Here are the arrangements adopted at the Paris station, which is at the head of the Orléans railway.

Let us first note that a train is made up of three kinds of carriages, which are placed in an order we will now indicate.

1° Wagons loaded with merchandise and baggage, included under the name of parcels office items.

2° Diligences and wagons carrying passengers.

3° Post-chaises which are placed on special small trolleys.

Upon departure, when the train is at DD' (fig. 11), the baggage wagons are therefore towards the end D'; and care has been taken to place near this end of building M, the rooms where the parcels office items are deposited. The wagons intended to receive them are therefore opposite the rooms where they are stored. Behind are the passenger carriages, also opposite the rooms where passengers wait. Finally, further behind, the post-chaises are placed, which are loaded onto the turntables P. Everything is thus conveniently arranged for service.

Upon arrival, the train is at AA'; the parcels office items are transported into the rooms where they are to be inspected by customs officers; passengers easily reach courtyard C where carriages are waiting; and the post-chaises which go towards end A are taken to the turntables Q where they are unloaded.

The track sections RR' are used to assemble the carriages. Turntables connect all these tracks so as to make service easy.

The construction and repair workshops are 1,200 m from the station at N; it was necessary to establish communications between the station and these workshops: this is the purpose of track EE'. It can be seen that it cuts the arrival track at Q: this is a drawback; care must be taken to cross this arrival track only when no train is in sight.

6th Lesson

Earthworks

We will only deal here with questions directly related to the construction of railways. — A care to be taken, and one that cannot be too strongly recommended in railways, is to drain the track as completely as possible. Ground softened and soaked by humidity allows the sleepers to sink, which, during the passage of a locomotive, can cause serious accidents. Water infiltrating the ground also promotes settlements and landslides. In the fine season, when the ground is very dry, very little re-ballasting is needed; on the contrary, it is needed after almost every rain, especially in the early stages of operation. It is therefore understandable how important it is to neglect nothing for the perfect drainage of the track. — Herein lies the safety of the railway and the security of the passengers.

Of the upper surface of the ground in embankment.

The slopes are at 1.5 base to 1 height. (fig. 12).

The upper surface of the ground on which the ballast rests is cambered and well leveled and smoothed to facilitate the drainage of waters that have passed through the ballast.

The ballast is leveled and regulated as was stated in a previous lesson.

On each side of the track there is a small bench, left for the circulation of trackmen. The main purpose of this bench, when the track is uncovered to lift the sleepers, is to prevent the materials, sand and stones, forming the ballast from flowing onto the slopes, where they are lost and harm vegetation.

These small benches are 0.50 m wide when the ballast is sand, and 0.75 to 0.85 m when the ballast is broken stone. In the latter case, the ballast slopes are replaced by small dry stone walls.

These benches also produce an economy on the price of the ballast by reducing the quantity of materials to be used in its construction; they promote the rapid drainage of water and consequently the draining of the track.

Case of cutting (fig. 13). The top of the ground is leveled as for the embankment profile, with a camber, i.e., in the middle of the track the ground is 0.45 m below the level of the rail and at the edge of the track 0.55 m. On each side of the track are ditches, 0.75 m deep. These ditches are necessary for drainage.

Small benches, 0.90 m wide, intended for the circulation of trackmen and to receive small landslides from the cutting slopes, are placed between the ditches and the foot of the slopes.

The slopes are dressed at 1 base to 1 height. For sand ballast, the slopes hardly hold at an inclination of 1 base to 1 height; they become gentler and slightly reduce the width of the shoulders.

The small dry stone walls that retain the ballast make it possible to widen either the axis or the bottom of the ditch, or to soften the outer slopes. It is essential to take precautions not to degrade the upper surface of the ground, prepared and leveled with a camber as stated above, when placing sand on the track. In the cutting where there are rocks or large stones, care must be taken not to leave them exposed; they must even be removed to a depth of 0.80 m below the level of the rails, in order to avoid any overhang of the sleepers.

Such are the general profiles for cuttings and embankments. But there are cases where it is necessary to modify them.

Thus, in the case of embankment, the slope is sometimes given $1\,^{3}/_{4}$ base to 1 height, and even up to 2 base, when the soil is very fluid or when there is an excess of earth.

Machines passing over large embankments sometimes impart to them a great tremor which tends to produce settlements, due to deformations which sometimes go as far as landslides. These landslides are particularly to be feared when the embankments are made of clay. Therefore, embankments of pure clay must be avoided as much as possible; clay should be mixed with ordinary soil or other material, in order to avoid the sliding surfaces that form in clay embankments and can cause very serious landslides.

It is very appropriate to place a small bench at the foot of embankments, when landslides are feared; when a landslide occurs, it almost always starts from the foot; and a bench consolidates the slope well.

When the foot of the embankment can be beaten by water during floods of a river, for example, this bench serves as a defense for the slope and should be placed slightly above the presumed water level during the flood. The Corbeil railway, at the entrance to the Orge valley and between Paris and Corbeil, presents applications of the foregoing.

In the case of cutting, the slope is sometimes given, but as rarely as possible, 1.5 base to 1 height. Sometimes even, in very poor ground, it goes up to 2 base to 1 height. It is for the engineer to decide on these exceptional cases.

When cuttings receive a large mass of water at their lower part, it is appropriate to give a depth of one meter below the rail, instead of 0.75 m, to each of the lateral ditches intended for draining the track. In this case, in order not to widen the bottom of the cutting too much, which can give rise to very considerable and very costly earthworks when the cutting is deep, dry stone walls should be built along the ditches; or, if forced for greater solidity to build masonry walls, care must be taken to pierce this masonry with numerous weep holes.

When the ground is poor, either in cutting or embankment, i.e., when it is of a nature to soften easily due to the presence of water, it is good to increase the thickness of the ballast layer on which the sleepers rest by 0.10 m to 0.15 m.

When the ballast is somewhat earthy or greasy sand, unsuitable for allowing water to filter through and to dry naturally, stones are placed inside the ballast to facilitate the drainage of water and the circulation of air, and consequently to dry the sand.

Means of consolidating slopes.

The means of consolidating slopes are:

1° To make them gentler, as already mentioned. This method has been indispensable in the case of clays which slid, and in the case of very fine sandstone sand, on which wind acted in a very harmful manner.

2° To cover them with topsoil to a thickness of 0.08 m to 0.10 m in order to promote vegetation. This method has been used successfully in the fine sands of Étampes.

3° To turf them or plant them.

4° To line them with dry stone pitching, when water beats against their foot; it is sometimes useful, in this case, to support the foot of the pitching with piles.

5° Sometimes it is essential to use small walls, buttressed against the walls containing the ballast by small arches; this frequently occurs in the case of fluid clays.

6° Fine wet sands sometimes filter through the joints of the pitching covering them. In this case, it may become necessary to support the slopes with small piles and small sheet piles.

There can be no fixed rules to establish for the use of each of these systems; it is for the engineer's experience to decide in each particular case; the goal that must always be kept in view is to ensure the drainage of external waters so as to completely protect the track.

It is sometimes essential to ram the earth, and the greatest care cannot be taken too much in this operation to avoid uneven earthworks. Notably in gaps filled in afterwards, such as ramps, trenches intended for drainage, etc.; near engineering structures; behind bridge abutments and inside wing walls.

Settlements occur when the railway is in operation; the track must be constantly re-ballasted to fill with sand the depressions that occur. This sand, which must be brought by wagons put into circulation at night, so as not to hinder operation, considerably increases expenses.

When embankment works are carried out by wagon, settlements are often very large; examples of earthworks that have settled one meter and 1.50 m after the laying of the track

have been seen. These enormous settlements greatly increase maintenance expenses due to the difficulty of transporting sand.

When embankments can be carried out in layers of 0.50 m or 0.60 m, and when at the same time transport is done by means of tipcarts, the passage of vehicles breaks up the clods of earth and exerts a kind of ramming very favorable to the immediate settling of the earth.

Means of transport for carrying out earthworks.

Wheelbarrows. This mode of transport is suitable for a distance of less than 90 to 100 meters. When distances exceed this limit, recourse must be had either to wagons or to tipcarts. We will not give the formulas used to calculate transport prices. The formulas for the case of wagons have not been applied by us on a large enough scale for us to give them as a basis for the calculations to be made.

The advantages of transport by tipcarts are:

1° to carry out transport with equipment found everywhere, which can be easily disposed of once the work is finished, and which allows a very large extension of the work without too much expense and difficulty.

2° to break up the earth well, to make it settle quickly and uniformly, in a word to make very good embankments.

The advantages of transport by wagons are:

1° to be much more economical, as far as the transport itself is concerned: a horse of ordinary strength can pull in a railway wagon 2 to 2.5 cubic meters of earth; in a tipcart and on ordinary ground, it will only pull 0.40 m or 0.50 m of earth. The difference varies all the more as the track is better leveled; but the loading and unloading of wagons often require shovel throws and even wheelbarrow transport; changing the position of rails, etc., finally, considerable and costly equipment, in wagons, railway, etc., which is very difficult to dispose of after the completion of the work. All these reasons mean that for short distances, the tipcart can advantageously sustain comparison with the wagon.

What is the distance for which it is appropriate to abandon the tipcart for the wagon? This we cannot say precisely. This distance obviously varies with the layout of embankments and cuttings, a layout which favors loading and unloading more or less.

2° To be able to be carried out in poor quality ground, in all possible weather, whereas transport by tipcart is, if not impracticable, at least very expensive when the ground is greasy and the weather rainy.

This is again one of those delicate questions whose assessment and solution are left to the experience and sagacity of the engineer.

7th Lesson

Engineering Structures.

General considerations on engineering structures.

They are, for railways, similar to those ordinarily carried out for roads and canals; only, in railways, even more than in canals and ordinary roads, it is important to have well-built masonry in which only good quality materials are used; the reasons for this are:

1° — that engineering structures on railways support, during the passage of locomotives, higher accidental loads than on ordinary roads and canals;

2° — that unevenness or irregularities in the laying, the joints of the rails which never connect perfectly, give rise to tremors which are likely to disjoint and damage poorly made masonry;

3° — Finally, that the maintenance and repairs of engineering structures are more difficult and more expensive on a railway than on any other means of communication.

Thus, good quality hydraulic lime and suitable for mortar, addition of pozzolana when the lime is doubtful.

Hard, resistant, and especially non-frost-susceptible rubble stone in masonry, and principally in facings, to a thickness of at least 0.40 m to 0.50 m.

Dimension stone in heads and copings.

Take into account, in the thicknesses of vaults and wing walls, the extraordinary heights, and the resulting loads of the earth that the vaults must carry and that the walls must support.

Give, in general, to vertical facings a batter of $^{1}/_{15}$ to $^{1}/_{20}$; avoid plumb walls, which always look like they are overhanging and which, at the slightest movement, do overhang in fact.

On vaults, reserve, for the sand layer above the extrados of the vault and its waterproofing, a height of at least 1 m up to the rail surface, so that there is, between the underside of the sleeper and the masonry, a sand thickness of at least 0.50 m to 0.60 m, forming a kind of cushion intended to absorb the shocks and vibrations that the passage of the engine can impart to the masonry.

When a vault is under a somewhat high embankment, adopt at both heads wing walls in preference to return walls; return walls are often pushed and spread apart, causing disjunctions in the body of the vault; wing walls, on the contrary, act as buttresses which counter-thrust the two heads of the vault and oppose the disjunctions that vibrations tend to produce.

When, in large viaducts, there are piers or pillars of great height, cut them, at intervals, by horizontal courses of dimension stone, forming as many superimposed arches, carrying the body of the pier properly speaking.

Waterproofing layers, 0.50 m to 0.60 m thick, must be made of first-quality mortar, carefully smoothed, so as to have neither cracks nor crevices; give these layers steep slopes; place some rough stones on their surface to facilitate the passage and drainage of water.

Necessity, to progress quickly, of adopting standard designs for all ordinary cases and making special designs only for exceptional or extraordinary cases.

Divide engineering structures into two categories:

1° Extraordinary works, i.e., those offering exceptional dimensions and requiring special designs.

2° Ordinary works, i.e., executed according to general types which are slightly modified when circumstances require it.

I. Extraordinary works.

High viaducts: Arrangement of abutments; thin return walls, 1.20 m to 1.50 m thick, carrying pointed arches, between which walls the embankment slope occurs naturally as on the outside, so as to avoid almost any thrust on the return walls; at the springing of the pointed arches, a good precaution we took was, for greater safety, to tie these return walls together with wrought iron tie rods, with large cast-iron plates at the ends forming nuts.

Enormous thrusts would be exerted on the return walls if the interval separating them were filled with embankments as in ordinary constructions.

Even for viaducts or bridges of little height, it is important to watch, with the greatest care, the nature of the earth placed between the return walls behind the abutments; there are clayey soils which swell with humidity and give rise to thrusts that nothing can resist; as far as possible, place in these places soils that are as permeable as possible, sandy soils, poor quality dry stones when available.

For tunnels, there are none on the Orléans railway; it would be outside my subject to speak of them, having in view, here, only the description of the works of the Orléans railway.

For bridges with large arches, I have not built any either; avoid them when possible; large arches are hardly indispensable except on navigable rivers; viaducts in valleys are preferably built with arches of only 8 to 10 m span; these arches are, in general, easier and more economical to build, of more assured solidity, especially in small materials, i.e., rubble stone, and finally less expensive to maintain.

II. Ordinary works.

Ordinary works can be divided into three classes:

1° – Level crossings;

2° – Bridges and culverts under the railway, either for the drainage of water, or for the passage of the public;

3° – Bridges over the railway for public circulation (It may also happen that a watercourse has to be taken over the railway; but this case must be very rare, if ever it occurs, since watercourses are always in low-lying areas and in these same low-lying areas railways are usually on embankments).

I. Level crossings.

Guard rails to hold the paving stones and metalling and thus ensure a free passage for the wheel flanges of both locomotives and carriages.

Arrangements adopted on the Corbeil line; chairs placed on sleepers like ordinary chairs; drawback that this arrangement presents for paving stones which, directly under the rails, do not have sufficient thickness.

Arrangements adopted on the Orléans line to remedy these drawbacks (see the attached drawing). (fig.)

Prefer, at level crossings, paving stones to metalling because of the small stones which, in the latter systems, can easily be thrown, either by carriage wheels or by horses' hooves, into the gap left between the rail and the guard rail for the passage of wagon wheel flanges.

Width of crossings:

For main roads . . . . . 8.00 m

For departmental roads . . . . . 7.00 m

For all roads, major communication roads, ordinary local roads, access roads, private roads . . . . . 5.00 m

For footpaths . . . . . 2.00 m

General arrangement of barriers, width 5.00 m, having only one leaf and able to close only the ordinary road, whether the crossing is straight or skew.

A) Exceptional arrangement of barriers: Barrier with two leaves capable of being closed at will, either on the railway or on the ordinary road, and always leaving open a width of 7.40 m (*) for the passage of the railway.

The great advantage of these barriers on crossings often traversed by herds of livestock.

Avoid, as much as possible, level crossings for main and departmental roads and for important local roads. Do not forget that a guard paid 800 to 900 francs per year represents a

(*) i.e., 3.70 m between the axis of the railway and the inner face of each fixed post, which gives between the faces of the two opposite and corresponding posts a width of 7.20 m for straight crossings, but which can become much larger for skew crossings.

capital of 15,000 to 18,000 francs; that a guard's house always costs 2,000 to 4,000 francs; that barriers, pavements, guard rails, etc., represent an expenditure of 2,000 to 3,000 francs and that ultimately a level crossing is equivalent to a capital expenditure of 20,000 to 25,000 francs; that these crossings also offer greater or lesser chances of accident and that ultimately a bridge over or under can often be a real economy.

II. Bridges and culverts under the railway.

These bridges and culverts can serve two purposes: for the drainage of water, either continuous or accidental, for the passage of a circulation route, public or private; very often they serve both purposes at the same time.

Culverts or underpasses specially intended for the drainage of water.

1° Cast iron pipes, 0.40 m, 0.30 m, 0.20 m, 0.10 m in diameter, apply to small watercourses, not susceptible to strong floods, or to small streams supplying ponds in private gardens.

It is important not to place them too close to the rail, so that the passage of engines cannot break them; on the other hand, they must not be sunk too deep into the ground, so that, in case of breakage, accident or any repair, they can be changed or repaired in one night, between the last train in the evening and the first train in the morning; we place them at least 1 m below the rail, and at most 2 m. When the height, between the bottom of the stream and the level of the rail, is more than 2 m, a vaulted masonry culvert is preferable to a cast iron pipe.

When a pipe passes under the railway with a strong siphon effect, as in luxury gardens, pipes supplying either elevated reservoirs or fountains, it is prudent to put, under the railway, a double pipe; a lead pipe, of the diameter required for the conduit, and an outer cast iron casing pipe; if the outer pipe bursts from any cause, the water can escape without gushing, in the form of jets of water, onto the surface of the track, where it could soak the ground, soften it and give rise to some accidents.

2° Small culverts of 0.70 m span, with the desired height, variable between 0.50 m and 1 m to 1.50 m below the rail.

The abutments of these culverts are masonry; the rails form, so to speak, the bridge; the chairs being placed on the faces of the two abutments and the rail having no support point between these two abutments.

The small wooden floor covering the interval between the two abutments, having the sole purpose of carrying a small layer of sand, in order to continue the track and not leave a gap there for trackmen or any other person following it on foot.

These small culverts are used in much the same circumstances as cast iron pipes.

To open or clean them, the wooden floor covering the interval between these two abutments is lifted.

3° Masonry culverts.

It is important that these culverts are not too small, so that a man can always, if necessary, inspect them and ensure that they give no cause for concern.

Our smallest masonry culverts have a width of 1 m and a height under the keystone of 1 m to 1.50 m, which represents, between the surface of the invert and the level of the rail, a distance of 2.20 m to 2.70 m; the thickness of the vault at the keystone, and the sand layer covering it, together forming a height of 1.20 m, assuming both reduced to their minimum; when the height is greater, the masonry culvert is built without difficulty with the dimensions, in width and height, necessary for the passage of water.

4° Culverts with masonry abutments and cast iron girder.

When the culvert must be wide and at the same time sufficient height is not available to build one or more masonry vaults, cast iron girders are used, bearing by their ends on the piers and abutments, and carrying the rails; the intervals between the girders being covered by a wooden deck; we will return to these girders shortly when speaking of bridges under the railway, intended for the passage of a public or private road.

Bridges or underpasses under the railway intended for the service of communication routes.

The dimensions fixed by the specifications for these bridges or underpasses are:

In width at least:

- for a royal road . . . . . 8 m
- for a departmental road . . . . . 7 m
- for a local road of great communication . . . . . 5 m
- for an ordinary local road . . . . . 4 m

The height from the roadway of the road is, for all these bridges, at least 5 m under the keystone when they are vaulted in masonry, at least 4.30 m under the girder when they are formed by a deck carried by cast iron or wooden girders.(*)

The width of passage of the railway on these bridges must be, between the parapets, at least 7.40 m.

The height of the parapets must be at least 0.80 m.

(*) I believe that this height under the girder of 4.30 m, a little low for carriages loaded with straw and hay, it would be appropriate, to amply satisfy all needs, to increase it to 4.50 m.
The dimensions in height and width for passages can then vary greatly and be reduced in certain particular cases, when the roads are only access roads or of minor importance, by means of amicable arrangements with the communes or individuals.

This width of passage for the railway and this height of parapets are and must remain the same, of course, for bridges under which, instead of being intended for the crossing of a road, would be intended for the crossing of a watercourse.

Build underbridges in masonry when possible, but note that an embankment height of nearly 7 m is required to build such a bridge without difficulty; indeed:

The height under the keystone must be at least . . . . . 5 m

The thickness of the vault at the keystone, the waterproofing, the cushion of sand interposed between the top of the masonry and the underside of the sleepers will occupy about a height of . . . . . 2.00 m

Total equal . . . . . 7.00 m

To increase the available height, the ordinary road is sometimes excavated under the railway, connecting the new ground with the old one near the bridge by means of more or less steep ramps.

When this arrangement is adopted, care must be taken to maintain drainage for the water and not to make the ramps too steep near the bridge.

The rules adopted in this respect are not to allow on new roads, slopes or ramps with a gradient exceeding 0.03 m/m for main and departmental roads, and 0.05 m/m for local roads.

On roads whose slopes before construction are steeper than the slopes indicated above, the administration has admitted a derogation from the rule it had laid down and it generally recognizes the right of companies to preserve, on the new roads, the slopes existing on the old ones, either at the very point where the deviation occurs, or nearby.

These rules, relating to slopes, are applicable to all cases where roads are deviated as a result of the construction of the railway.

When the embankment height is more than 7 m, there is always reason to build masonry bridges.

It can be understood that the height under the keystone can then be, without inconvenience, greater than 5 m and rise to 6, 7, 8, 9 meters or more; we have viaducts with a height under the keystone of up to 10 and 16 m.

The engineer is, as can be felt, free, when the embankment height is thus greater than 7 m, to choose the height under the keystone he sees fit to adopt, except to vary, consequently, the length of the vault.

For large multi-arch viaducts, there is generally an advantage in bringing the height under the keystone to its maximum.

For single-arch bridges or culverts with a small span, there is an advantage, on the contrary, in making the vault as low under the keystone and consequently as long as possible, with wing walls.

Skew bridges.

Means of avoiding them, which is good to use when only small materials are available; slightly lengthened straight bridges are built.

Bridges with cast iron girders and wooden deck.

On the Corbeil line, we built bridges with wooden girders and deck; but I believe that wooden girders, which I only adopted for reasons of economy, are bad and that cast iron girders should be preferred, given the difficulty of renewing them.

As for the wooden deck, it can be maintained and renewed without stopping traffic; it does not seem to me to present any drawback.

Our cast iron girders are of two types: those that carry the floor above the girder and those that carry it by means of bottom flanges (see drawings of these two systems) (fig. 14).

The thickness, between the underside of the girder and the top of the rail, is in the 1st system 0.68 m

Namely: Height of the girder. . . . . 0.45 m (variable with span)
Thickness of the floor 0.08
Thickness of the chair baset 0.04
Height of the rail 0.11

Total equal . . . . . 0.68 m

And in the second system, of . . . . . 0.34 m

Namely: Bottom thickness of twin girders . . . . . 0.04 m
Thickness of the wooden soleplate intended to carry the chairs and to form a kind of cushion on the cast iron 0.15
Thickness of the chair base 0.04
Height of the rail 0.11

Total equal . . . . . 0.34 m

The bottom flanges are intended, as can be seen, to reduce as much as possible the thickness of the supporting system, and thus increase the available height for the passage.

It is only a matter of giving the castings sufficient dimensions; this is what we did, as can be verified by calculation.

The girders are bedded on a layer of Pouilly cement, bearing on the dimension stone.

Advantage of these girders for skew bridges.

We used girders having a span of 6 m

5 m

4 m

3 m

2 m.

III. Bridges over the railway.

The width of these bridges, between the parapets, is, as for underbridges,

For a main road . . . . . 8 m.

For a departmental road . . . . . 7 m.

For a major local communication road . . . . . 5 m.

For an ordinary local road . . . . . 4 m.

The width of passage of the railway, between the two abutments, is 7.40 m.

The vertical height between the top of the rails and the underside of the bridge, whether masonry or timber, must be . . . . . 4.30 m.

On the Orléans railway we adopted . . . . . 4.80 m.

This height is necessary for a large diligence, with its open cabriolet, mounted on an ordinary trolley, to be able to pass under the bridges.

When height is available, these bridges can be built in masonry; but, in general, it is better to build them in timber, so as not to obstruct the view.

(See the design of our bridges for the Orléans line) (fig. 15).

The drawback that can be criticized in this design, and which should be remedied, is the use of timber beams; it would be preferable to adopt cast iron beams, so as to have to maintain and renew only girders and a floor which can be removed and replaced without in the least hindering traffic on the railway.

The removal and re-installation of the trestles is, on the contrary, likely to give rise to some difficulties.

This design applies to skew bridges as well as to straight bridges, taking care, for skew bridges, when the span and consequently the beam spans increase significantly, to substitute stronger beams or twin beams for the single beams shown in our drawing.

Bridges to be built at the intersection of main and departmental roads must be in masonry or iron.

Essential difference between overbridges and underbridges, in that the former can be maintained and renewed without hindering traffic, whereas the same is not true for the latter; hence the fact that we used cast iron for the beams in underbridges and wood for the beams in overbridges.

About a bridge at Étampes under which pass 3 tracks and whose central span has an opening of 12 m. Suspension system under the beams; iron wire cables attached to the two

ends of the beam, the tensions of the chain being maintained in equilibrium by the beam, the system exerts no tensile force on the piers.

Footbridge for pedestrians, 2 m wide, also having a 12 m span; braced girders forming the guardrail.

8th Lesson.

The first question to be solved, for the establishment of a railway, is the exact determination of its axis.

So many considerations must influence this determination that it is difficult to enumerate them here; there is always a happy medium to be sought between perfection in the layout, which is generally, the straight line in plan, and the level in profile, and the expenses required by this perfection.

Curves in plan and ascents and descents in profile are adopted to avoid sometimes impracticable, most often only very costly, works; but these curves and gradients must be used as little as possible.

For a passenger railway, where trains running in one direction are generally equivalent to trains going in the opposite direction, a level layout, or one approaching it as closely as possible, is best.

For a goods railway, on the contrary, it may happen that transports are much more considerable in one direction than in the other, such as the Saint-Étienne to Lyon railway, whose main purpose was the transport of coal from the Saint-Étienne basin to the Rhône; for such a railway, it is evident that a more or less steep gradient, in the direction of the greatest movement, is preferable to a level.

As almost all railways serve both passengers and goods, the engineer has to take into consideration, in the choice of his layout, all the probable elements of transport he can foresee and then settles his ideas accordingly.

Almost always, the difficulties of the terrain do not leave this choice all the desired latitude and impose on the engineer the layout he must follow.

When dealing with the question of locomotives, we spoke of descents and ascents, of the gradients it is appropriate to adopt in given circumstances and of the influence that these descents and ascents exert on traction; we will not return to this subject.

We will only point out that sometimes, to facilitate the construction of an engineering work, one allows oneself to break the uniformity of the profile in ascent, descent, or level, and that one introduces near this bridge, an ascent and a counter-ascent of a few hundred meters having a steeper gradient than the normal gradient of the section of railway in which one is located.

An engine, by virtue of its acquired speed, overcomes without difficulty such an irregularity which often greatly facilitates the construction of an engineering work; we have not had occasion to use this facility on the Orléans line; but we know that it has been allowed on several English railways and we indicate it because it does not seem to us to present any serious drawback; however, it should only be used when there is a real necessity.

For curves, the minimum radius imposed on us was 800 m; we adopted 1,000 m; in depots and stations for service tracks, smaller radii can be adopted (and one is often obliged to do so); we have sometimes allowed radii of 500 and even 250 meters; but we did so as seldom as possible.

When there is a curve with a radius of 2,000 to 2,500 m, it is useless to seek better; recourse to curves with a larger radius should therefore only be made when the terrain demands it and when a curve with a very large radius is likely to place the layout on perfectly suitable ground, which sometimes happens.

Curves are set out by coordinates; it is for the engineer to choose axes so as to simplify the layout as much as possible, having regard to the difficulties of the terrain; it is understandable with what accuracy the bases of the operations on which the layout is established must be recorded.

When the axis is well determined on the ground; when the longitudinal profile has been carefully surveyed, the width of land to be acquired for the establishment of the railway itself and its appurtenances must be fixed at each point.

I will explain what I mean by its appurtenances; these are:

1° Sidings and standing depots for the stabling of locomotives and wagons, for the embarkation and disembarkation of passengers, for the loading and unloading of merchandise and livestock; finally, for all the needs of the operating service, which the engineer must try to foresee as best he can.

2° The ditches necessary to restore the course of waters where it is modified as a result of the construction of the railway; it often happens that in order not to multiply culverts too much, several small watercourses are combined into one by lateral ditches along the railway; for the digging of these lateral ditches, land sometimes also has to be purchased, or a watercourse has to be diverted to choose a suitable point for the foundation of a culvert (example: the Louette and the Chalouette at Étampes, where these two small rivers were diverted to the foot of the hills bordering the valley, instead of leaving them in the middle of this valley, where they were originally located; it was also possible to found the two viaducts of the Louette and the Chalouette on solid ground, whereas in the middle of the valley only ground incapable of resistance was found, with a thickness of more than 20 meters; there is also reason, in such a case, to purchase the land necessary for opening new beds).

3° Road deviations, to facilitate the construction of an engineering work; lateral roads 3, 4, 5 and sometimes 8 m wide, often indispensable for the service of properties cut by the railway, and very useful for reducing the number of crossings to be established on or under the line; in inquiry commissions, it is

often necessary to offer such roads to obtain the suppression of crossings; great economy is found therein.

4° Deposits and borrow pits, when they can be foreseen in advance, it is good to include them in the parcel plans, especially for enclosed land, for which such works are only chargeable to the owners through expropriation.

For the railway, the width of the railway itself must be purchased, which is 8.30 m in embankment and 12 m in cutting, with the small lateral ditches, their slopes and their benches.

Plus the space for the slopes; to guard against any chance of landslide, we calculated

1° embankment slopes at 2 base to 1 height, although in execution we only gave these same slopes 1.5 base to 1 height;

2° cutting slopes at 1.5 base to 1 height, although in execution we only gave them 1 base to 1 height; this excess width of land is intended to allow the slopes to be made gentler when the need arises, without resorting to new expropriation.

Plus, two benches at the foot of embankment slopes and at the top of cutting slopes; these benches have, for embankments, a width of 2 m, and, for cuttings, 3 m on the valley side; this excess width, on the hillside, is intended to allow the establishment, if necessary, of upper ditches to receive the waters and prevent them from falling into the cutting.

These benches are used for planting hedges for enclosures, which require 1 m, and for a small circulation path for people guarding and watching over the railway.

It can be seen that to determine the widths of the lands to be acquired, cross-sections are necessary; if the ground were level or nearly so, the width of land to be acquired would be represented:

in embankment, calling h the height of the railway at the point considered, by the formula

$$8.30\ m + 4\ h + 4.00\ m = 12.30\ m + 4\ h\ .$$

half of which on the left and half on the right of the railway axis.

in cutting, calling h the depth of the cutting at the point considered, by the formula

$$12.00\ m + 3\ h + 5.00\ m = 17.00\ m + 3\ h\ .$$

of which $8\ m + \frac{3\ h}{2}$ on the side of the axis where the valley lies and $9\ m + \frac{3\ h}{2}$ on the side of the axis where the hillside lies.

When this ground, instead of being level or nearly so, offers a transverse slope, the above formulas must be modified and the width of land to be acquired calculated according to the shape presented by the ground on which the railway is to rest, always starting from the same hypotheses with regard to the inclinations of the slopes and the widths of the benches.

In exceptional cases where there is valuable land or buildings to be acquired, the width must be reduced to the strict minimum by steepening the slopes by means of stones or retaining walls, and by reducing the benches.

When crossing parks, only reduce it when there is evident economy; because certain owners consider all the damage to be in the crossing or cutting of the park itself and more or less disregard the surface area.

In such cases, the inclinations of the owners must be sounded and action taken accordingly.

When the limits of the required land have thus been exactly fixed, lateral roads, lateral ditches, road and stream deviations, sites necessary for the construction of engineering structures and the establishment of their approaches, lands to be used for borrow pits or deposits, areas for standing and sidings depots have been decided upon, all that remains is to draw up the projects which must be submitted either to the higher administration or to local inquiries.

I will give here the list of documents which must form part of a project.

It would be desirable that the frameworks of these projects, the scales of the plans and profiles, the indications they must contain, be decided in advance, in order to remove all uncertainty and hesitation from the engineer.

It will be indicated here how the projects for the Orléans railway were drawn up, leaving engineers free to imitate or correct them if they see fit.

No mention will be made here of the plans relating to the inquiries ordered by Article 3 of Title *I* of the expropriation law of May 3, 1841; inquiries whose purpose is to obtain the opinion of local communities on the general direction of the layout.

It is understood that these plans must vary with the extent of the line to be submitted to inquiries; thus, to submit to inquiries the general layout of a railway, from Paris to Lyon, for example, following either the Yonne valley, or the Seine valley, or finally the Aube valley, a plan on a very small scale is needed, resembling a map more than a plan; then there are detailed plans on a larger scale for the parts presenting real difficulties and likely to become, during the inquiries, the subject of discussion and serious examination.

For our Orléans railway, the inquiries took place on plans drawn up on a scale of $\frac{1}{10.000}$ or 0.001 m for 10 meters.

The file submitted to the administration includes, besides the plan in question, a longitudinal profile on which the same scale as for the plan, i.e., 1 to 10,000, is adopted for horizontal distances, and for vertical heights, the scale of $\frac{1}{1.000}$ or 0.001 m per meter.

To the topographical plan and the profile just mentioned, an explanatory memorandum is attached, which is the important document of the project, and in which the reasons which led the engineers to adopt one layout in preference to all others are set forth.

Attached to these projects are detailed plans for the exceptional and important parts of the project, on which it is desired to draw the attention of the inquiry commissions, either to have the project accepted or rejected.

Of the topographical plan.

When a general layout has been decided upon, detailed studies must be carried out.

For this purpose, topographical plans are submitted to the administration, representing the layout in a more precise, more detailed and more complete manner than in the first project; it is important, as much as possible, that this project is no longer modified, except for some details relating to works affecting the communes.

The file of topographical plans consists of:

I. A plan on a scale of 1 to 5,000 or 0.0002 per meter indicating:

1° the axis of the railway, traced with all possible accuracy;

2° the radii of all curves and the tangent point with the straight alignments;

3° the approximate widths of lands to be acquired, with the locations of sidings and standing depots;

4° the crossings for traversing the railway, either over, under, or at grade;

5° the structures for water drainage and finally all the engineering works that the establishment of the railway may require;

6° the locations of the cross-sections attached to the project to give a general idea of the shape of the ground;

7° the extremities of descents, levels and ascents are indicated by the letters a, b, c, etc., serving to connect the plan with the accompanying longitudinal profile;

8° the boundaries of communes, arrondissements and departments.

These topographical plans cover a length of 15 to 20,000 m and encompass the crossing of the railway through several communes, but they should only apply to one arrondissement, given that they are deposited in the sub-prefectures of each arrondissement with the inquiry plans.

II. A sheet of profiles representing the longitudinal profile, on a scale of 1 to 5,000 for horizontal distances and of 0.001 m per meter for vertical heights; on the longitudinal profile are marked by the letters a, b, c, etc.... the extremities of the descents, levels and ascents serving as points of connection between the profile and the plan.

On the longitudinal profile are represented:

1° On a first horizontal line, the names of the communes, with the lengths of their sections crossed by the railway.

2° Engineering works of all kinds, for the service of communications intercepted by the railway and for water drainage;

3° Levels and descents and ascents, with indication of their gradients and their respective lengths.

4° Then comes the profile itself, representing embankments in red and cuttings in yellow.

5° The red elevations of the railway axis, related to the mean sea level at Le Havre; the black elevations of the natural ground, at the corresponding point; and finally, the differences between the red elevations and the black elevations, or the cutting and embankment depths.

6° Finally, a horizontal line representing the mean sea level at Le Havre, with the horizontal distances separating the ordinates whose elevations have been given.

Below the longitudinal profile, cross-sections are shown at intervals, drawn on a scale of 0.001 m per meter, and representing above all the important embankments and cuttings of the layout as well as the shape of the ground at points where they present exceptional features.

III. An explanatory schedule of the works to be executed for the establishment of the railway.

This schedule includes:

1° the general description of the layout and the designation of the localities it crosses or passes near.

2° The geometrical description of the layout in plan.

This is a table with several columns representing the straight alignments, and their lengths; — The curves and their developments; the curve radii; the versine, the chord and the tangents of each curve; the angles made by consecutive alignments, with an indication of the direction in which they are formed.

By means of this table, the exact geometrical layout of the railway in plan must be reproducible.

3° The table of ascents, levels and descents.

This table is a record of the longitudinal profile; it indicates the lengths of the descents, levels and ascents; their gradient; the products of the gradient by the length, i.e., the amounts by which one rises and descends by means of each ascent or each descent; and finally the red elevations at the extremities of the descents, levels and ascents.

By means of this table, the longitudinal profile of the railway must be reproducible, disregarding, of course, the shape assumed by the natural ground.

In this same chapter, the description of the cross-section adopted for the railway, both in cutting and in embankment, is given.

4° The engineering structures to be built for water drainage or for maintaining communications, indicating the nature of each structure, its dimensions in width of opening, in length or in width between parapets; height under keystone or under girder, height of the rail above or below the natural ground at the point where each work is to be built; and finally a few words of explanation on the exceptional features that each engineering work may present, either by itself, or by the works that its approaches may require.

5° Finally, the locations of standing and sidings depots, with an approximate indication of their extent and the reasons for the positions chosen for their establishment.

When the projects of the topographical plans have been submitted to the administration and approved by it, the parcel plans must be drawn up which, under the terms of Title II of the expropriation law, must be submitted to local inquiries; these plans are accompanied by various documents necessary to satisfy the requirements of the law and to give the interested parties, i.e., the communes and owners whose lands are crossed by the railway, a clear idea of the damage that may be caused to them and of the manner in which their lands are affected.

The files of the parcel plans include:

1° The parcel plans themselves of the lands or buildings whose transfer is necessary for the establishment of the railway.

The plans, drawn up on a scale of 0.001 m per meter, must exactly indicate the limits of the lands to be acquired (limits fixed or determined according to the considerations we developed above).

These plans are generally extended a little beyond the limits necessary for the establishment of the railway, so that if, as a result of an accident, widening becomes necessary, additional land can be acquired without preparing new plans.

It is important that these plans be prepared with the greatest care; that the axis of the railway and the limits of the lands to be acquired be exactly shown thereon; that all changes the limits may undergo during the course of the works be constantly represented thereon.

One would hardly believe how many lawsuits arise after the completion of works over the fixing of boundaries; lands acquired by a work of public utility are inalienable, and after a hundred years of encroachment by an owner, the administration is still entitled to claim the restoration of its boundaries; now, riparian owners of canals and railways are very inclined to encroach upon the benches or rights-of-way existing along these railways or canals, and these encroachments give rise to continual lawsuits, which take up an enormous amount of engineers' time.

With parcel plans well prepared in the beginning, corrected or modified with care when necessary during the execution of the works, many lawsuits, many difficulties, much wasted time are avoided; this matter cannot be too strongly recommended to the attention of our young engineers.

The files relating to the deposit of parcel plans in the communes include:

1° The parcel plans we have just spoken of, with indication of depots of all kinds, lateral roads, engineering works, etc., intended to maintain existing communications and water drainage.

It is understood that it is important to make known to the interested parties how the existing communication routes will be maintained and modified and how water drainage will be preserved or restored.

2° The table of parcels occupied by the railway, with indication of the names of the owners, as they are entered in the tax roll, as the law requires, of the real owners, if they are known; of the area of each parcel and of the surplus, when these surpluses are approximately within the limits fixed by the law.

3° Longitudinal and cross profiles, on the scale of the parcel plan, both for vertical heights and for horizontal distances (0.001 m per meter), with indication of engineering works of all kinds; the longitudinal profile explains the necessities that may have been experienced for the construction of certain engineering works.

4° Finally, an explanatory memorandum including the indication of the layout, a plan, with its curves and straight alignments, the indication of the longitudinal profile, with its levels, its descents and ascents and their gradients; the indication of the engineering works, with an indication of the means to be employed to maintain existing communications and to ensure water drainage.

A separate, distinct file is required for each commune.

When the crossing of a commune is too long or contains many curves, it is impossible to represent on a single sheet all the lands necessary for the establishment of the railway; the plan must then be made in several sheets and it is appropriate to attach to the file a general plan of the crossing of the commune, on the scale of the topographical plans (1 to 5,000) presenting the assembly of all the parcel plans.

This general plan is also necessary to give the commissions a clear idea of the use and situation of the roads to be served and which are often to be diverted or suppressed.

...that the forces opposing the movement do not exceed the limits of adhesion of the transmissions on the rails...

Notes taken during the railway course

1842 - 1843

In the presentation that Mr. Jullien made at the school of the works executed for the establishment of the Orléans railway, he gave numerous and interesting details on the generally adopted arrangements, and particularly realized on the Orléans railway, for the constitution of the track, the execution of earthworks and engineering structures, the establishment of depots, track crossings, etc., etc... He had, moreover, preceded this presentation with extensive developments on the theory of the locomotive engine, as it was originally conceived and published by Mr. Guyonneau de Pambour.

This will dispense with returning to these questions in the lessons which will follow. The aim will only be to treat a small number of fundamental questions, which are sufficiently defined by the following subheadings:

Of the principles which should govern the determination of railway layouts.

Of the drawbacks and dangers resulting from transition curves; and of the means proposed to facilitate the circulation of trains in curves of small radius.

Of the various systems proposed or put into practice for the establishment of the iron track.

On the drafting of projects.

Of the principles which should govern the determination of railway layouts.

Opportunity was taken to insist, in the roads course, on this important observation that for any means of communication, the road itself, and the vehicles and motors intended to use it must be considered as the interdependent parts of a single mechanical whole; so that if one of the elements varies, each of the other two must almost necessarily be modified. It is especially when it comes to railways that this truth is palpable, and stating it is, in a way, sufficient.

The conditions according to which railway layouts must be established depend directly on the influence exerted on the running of locomotives by the undulations of the longitudinal profile, in elevation and in plan. It is therefore appropriate to study this influence. For this, we will not return to the formulas previously given; we will only present numerical results, either deducing them from these formulas or easily determining them a priori.

Let us first examine the motion of a locomotive hauling a train on a level line and see the effect it is capable of producing, either in terms of the effort exerted or in terms of speed.

For the locomotive to start moving, two conditions must be fulfilled: first, the effect to be exerted to initiate motion must not exceed the limits of adhesion of the driving wheels on the rails; second, the impulsive force of the steam on the pistons must at least balance the sum of all the resistances opposing the motion of the pistons. Each of these conditions sets, for determined states of the engines and rails, a value that the effort corresponding to the load must not exceed. These two values thus obtained are generally different. The lesser of these two values represents the maximum effort the engine can produce.

Suppose it is a question of an engine of 16 tons, having wheels 1.67 m in diameter, and pistons 0.355 m in diameter with a stroke of 0.508 m, as the engines of the Orléans railway are to be. - Quite generally, the driving wheels of 6-wheeled engines carry 0.55 of the engine's weight; in this case, 8,800 kg. — Adhesion can vary, depending on whether the rail is dry or greasy, from the most favorable to the most unfavorable circumstances, between $^1/_5$ and $^1/_{15}$ of the weight. If we take as an average figure $^1/_{10}$, the limiting value of the external resistances that the engine will generally be capable of overcoming, with regard to adhesion, will be 880 Kilograms.

If, on the other hand, the impulsive force of the steam on the pistons, parallel to the direction of travel, is calculated, one will find (at the maximum effective pressure; say 4 atmospheres) 1530 Kilograms, deducting 112 kilograms for the engine's own resistance, over 1400 kg remain for the maximum effort it would produce, if sufficient adhesion could occasionally be obtained. It can be seen that, in the present state of loads, insufficient adhesion singularly reduces the use it would be possible to make of the real power of the engines; and that, consequently, an eminent service would be rendered to the railway industry if, in circumstances where the engine must produce considerable efforts, it were possible to notably increase adhesion, without increasing rolling resistance in the same proportion.

It is understandable that if adhesion became equal, for example, to one-fifth of the weight supported by the driving wheels, all the engine's force could be utilized.

The greatest effort that could today generally be exerted (i.e., in the ordinary condition where adhesion = $^1/_{10}$ of the weight supported by the driving wheels) by a 16-ton locomotive designated as above and traveling on a perfectly horizontal level, would correspond to pulling a train of 260 tons at a speed of a little over 5.00 m per second.

Indeed, the direct resistances, the sum of which must not exceed the adhesion limit, are in this case:

1° For pulling 270 tons including the tender, at 3 kg per ton 810 kg

2° For wind resistance . . . . . 87.45 kg

In sum . . . . . 897.45 kg

an effort which, as can be seen, already exceeds the value previously found for the adhesion limit of the engine on the rails.

The useful work exerted in this case by the engine is expressed by 810 kg x 5 m = 4050 kgm, which corresponds to the effective force of 53 steam horsepower. If the action of the steam on the pistons were evaluated directly, a nominal force of 75 horsepower would be found. The useful effect is therefore 70%; moreover, the truly useful load, the one for which transport is paid, is only $\frac{3}{5}$ at most of the weight hauled: according to the ratios of the weights of empty or loaded wagons on the Orléans railway, it would be reduced to about 130 tons.

The least effort the engine can exert corresponds to pulling the tender. It was previously calculated (page 11) that the speed would then be about 16 leagues per hour, on horizontal ground, and the air being still; i.e., for the sole action of the steam. It is understood that this refers to the engines mentioned above: with engines having larger wheels and a greater vaporization power, speeds of 25 to 30 leagues per hour could be obtained.

If the engine is called upon to exert an action comprised between the effort limits just set, what is considered at the start, at the moment when the engineer opens the regulator, the steam being at maximum tension, the engine's mechanism is immediately seen to start very slowly, the driving wheels turn without slipping and pull the tender and communicate a movement to the first carriage, which is transmitted, weakening from one to the next, to the following carriages. From that moment, each new impulse of the steam determines an increase in the speed of the movement, but soon, the steam consumption by the cylinder increasing and the steam tension in the cylinders dropping at the same time as the speed increases, a uniform speed is established and henceforth permanent as long as the state of the train, the rails, the wind and the engine do not change; and which is such that, on the one hand, there is equilibrium between the steam tension in the cylinders and the sum of the resistances opposing the motion of the pistons; and, on the other hand, equality between the weight of water usefully vaporized by the boiler and the weight of steam consumed by the pistons. These are the laws of this uniform motion that were given previously.

Suppose now that a more or less considerable train hauled thus with uniform speed on horizontal ground suddenly encounters an ascent; at that very moment the resistance increases; the steam tension in the cylinders is no longer sufficient to balance the sum of the developed resistances; the speed slows progressively until (if the ascent is not too steep and is long enough) a new uniform speed is established suitable for the new conditions in which the engine and the train find themselves. During the progressively retarded motion, the train consumes a greater or lesser part of the quantity of work represented by the previously acquired kinetic energy. If the ascent were both very long and very steep, it could happen that this quantity of work in reserve was no longer sufficient to help the locomotive overcome the obstacle; moment by moment the speed would decrease; the steam tension in the cylinders would constantly increase; and would soon reach such a value that, insufficient to balance the resistances, it would be more than capable of overcoming the resistance to wheel slip; adhesion being overcome, the wheels would spin in place and immediately slip on the rails while going back down the slope, all the while continuing to turn in the same direction.

If, instead of being equal to $^1/_{10}$ of the weight supported by the driving wheels, adhesion were equal to $^1/_5$, the effects would be different: the steam tension in the cylinders would increase until it became equal to the tension in the boiler; the valves would lift; a more and more considerable portion of the vaporized water would escape uselessly; the speed falling well below the lower limit corresponding to normal steam usage conditions, would end up becoming zero and negative, and the train would either stop or go back down the ascent, the wheels, even the driving wheels, turning without slipping in the opposite direction to that in which the steam would tend to make them turn; the latter then would only play the role of moderator and brake. It is well understood in which case the engine would stop: it is in the case where the forces developed by the steam and by gravity do not differ enough from each other for the excess of the larger over the smaller to overcome the proper resistances that the engine would have to develop functioning under the double action of these opposing forces. It is quite clear, moreover, that if the circumstances just analyzed presented themselves, the train would in no case be allowed to go back down, and by the aid of brakes it would be held in place until one or more relief locomotives could be brought. External resources that could be used in these exceptional cases were only disregarded to make the engine's mode of action more completely understood, and the obstacles that ascents can present to the locomotive.

When ascents are long enough that the influence of the speed acquired in earlier periods of the motion cannot be felt up to their upper part, they have the consequence of obliging a considerable reduction in the weight of the trains that locomotives could haul; unless operating circumstances permit the advantageous use of helper engines. Thus the locomotive which can haul on horizontal ground 128 tons of useful load can only haul 60 tons of useful load on an ascent of 3 millimeters per meter, 36 tons on an ascent of 6 mm/m, 24 on an ascent of 9 and 17 on an ascent of 12. On an ascent of 32 mm/m, the locomotive could no longer haul itself (followed by its tender).

Suppose finally that after having taken uniform speed on a horizontal level, or after having climbed an ascent, the locomotive arrives at the top of a descent, the speed will increase; the acceleration of motion will continue until the speed has reached a limiting value which will vary according to the length and steepness of the grade, and the more or less open setting of the regulator. In general, it is not intended to give the train a speed of more than 10 m per second; now, this speed can be maintained by gravity alone and notwithstanding air resistance, on a descent of 0.0046 m/m. If therefore the descent is equal to 0.0046 m/m, steam will be used until the progressively increasing speed has reached 10 m; and from the moment this degree of speed has been acquired, the regulator will be closed. If the descent is below 0.0046 m/m, the regulator must no longer be closed but considerably reduced. If the descent exceeds this limit, the rapidity of motion, if moderated by brakes, will exceed the desired speed, without the locomotive functioning; and it will become all the greater as the steepness is greater; provided, however, that the descent has sufficient length. The only acting forces are then gravity and air resistance - the accelerating force is expressed by

$$\frac{dv}{dt} = g\left((i - K) - \frac{u}{m + M}\, v^2\right) \qquad (1)$$

expression in which g is gravity, i the inclination of the descent, K the coefficient of friction, $\underline{ug}$ the resistance opposed by the air to the train moving with unit speed, m and M the respective masses of the locomotive and the rest of the train.

Moreover, for the distance traveled

$$d\epsilon = vdt = \frac{1}{g} \cdot \frac{Vdv}{i - K - \frac{u}{m + M}\, v^2} \qquad (2)$$

If one counts on air resistance to stop the train on a descent, $\frac{dv}{dt}$ must become zero. By setting therefore $i - k = \frac{K}{m + M} v^2$ we will have for each value of i the speed at which the uniform motion of the train will be established, under the sole actions of gravity and air resistance.

If the calculation of these values of v is made, assuming it is a question of a train of 12 carriages of such weight that the whole train, including the locomotive and the tender, is 80 tons, it is found that:

On a descent of	0.01 m/m	the speed will be	20.66 m	per second
"	0.02 m/m	"	32.20 m	"
"	0.03 m/m	"	40.58 m	"

These are speeds of 18, 29 and 36 leagues per hour. — Such speeds, as can be ascertained by a few experiments, do not <u>necessarily</u> entail fatal consequences; but they are at the very least frightening. — The last, that of 36 leagues per hour, is the speed a falling body would have at the end of its fall from a height of 81 m.

Be that as it may, it must be noted that the degree of speed at which air resistance balances the component of gravity acting on the train can only be attained on condition that the descent has a certain length.

The integral of expression (2) above is, as is known, assuming the initial speed at the top of the descent is zero:

$$\epsilon = \frac{1}{xg\ \frac{u}{m + M}}\ I\left[\frac{i - k}{i - k - \frac{u}{m + M} \cdot v^2}\right]$$

I denoting a natural logarithm.

One deduces from this that, under the preceding assumptions (those of an 80-ton train of 12 carriages, starting from the summit with zero speed), the train descending a descent of 0.01 m/m will reach:

Speed of	5 m/s	after traveling	188 m
"	10 m/s	"	830 m
"	15 m/s	"	1990 m
"	20 m/s	"	8600 m

If, instead of assuming the speed at the top of the descent to be zero, it is assumed to be 5 m/s at the moment of departure (assuming in this case as in the previous one that the steam ceases to act upon arrival on the descent), the following figures would be deduced from the above figures:

Speed will be	10 m/s	after a run of	642 m
"	15 m/s	"	1802 m
"	20 m/s	"	8412 m

It can be seen that an inclined plane of 0.01 m/m must be of considerable length for a train to acquire a dangerous speed on it under the action of gravity; a descent of this inclination over 2000 meters in length, if it were followed by a counter-ascent or a level line of a certain extent, would present very little inconvenience in descent.

It is perhaps good to add that if the train were composed of a smaller number of carriages or of a lesser weight, even greater distances would be required to attain the same speed; because the accelerating force would have diminished proportionally more than the air resistance; just as, on the other hand, the steep slopes which are so disadvantageous for climbing for goods trains also have the drawback of being even more dangerous in descent for these trains than for passenger trains.

From the discussion just conducted, consequences emerge almost by themselves which it is important not to lose sight of when dealing with railway layouts.

In principle, slopes that are at all pronounced are very disadvantageous for the perfect operation of a line; but the importance of the drawbacks they present varies singularly, according to the nature of the operation: steep slopes are, generally speaking, extremely unfavorable for goods trains because they oblige a considerable reduction in the mass composing each train; they are much less prejudicial to passenger trains, because these trains almost never travel at full load, always having an excess of force reserved for the difficult parts of the journey. In this latter case, slopes only result in a reduction in speed which, as long as the ascent is not too long, has little effect on the total journey time. — However, this increase in travel time could in given cases become notable, for the time taken to travel a kilometer on an ascent of 0.003 m/m is 32 to 34% longer than the time necessary to travel a horizontal

kilometer; on an ascent of 0.006 m/m the increase in time is 70%; on an ascent of 0.011 m/m the time is doubled.

In all cases, one consequence of slopes is to notably increase fuel consumption.

A slope of a given inclination cannot, in general, be rejected for the sole reason that it is more or less steep; for, it should have been seen, from what precedes, that it is less important to consider the steepness of a slope than its position and length. If an ascent is very short and placed following a descent in the opposite direction, it will be overcome, even if very steep, without difficulty and without appreciable slowing of the speed, by virtue of the speed acquired by the train. The same ascent, of given inclination and length, may or may not be accessible to locomotives, depending on whether, by reason of its position on the line of travel, it can be approached by trains with or without acquired speed: thus on the Liverpool railway, the inclined planes of Sutton and Rainhill (with an inclination of 0.0104 m/m over a length of 2.5 kilometers), are negotiated by locomotives, while on the same line, at the exit from Liverpool, an inclined plane of the same slope and the same length (0.0113 m/m over 2.2 kilometers) is worked by stationary engines.

When steep slopes have to be short, it will be a happy circumstance to be able to place them at the foot of stations: because, on arrival, trains will use up their speed on the ascent; on departure, they will regain their running speed more quickly.

When steep slopes have to be long, it will be preferable, on the contrary, for stations to be at their foot, especially if they are stations of some importance, because trains will have to pick up helper engines there.

It is enough to be put on the track of such considerations to find for oneself the combination to be sought or avoided with a view to economical operation.

It will often be best, when circumstances permit, to adopt no slope that creates an anomaly in the general system of inclinations allowed on the line. — However, if an exception is absolutely necessary, it will almost always be better to resolutely adopt a steep slope than an intermediate slope, even if in execution one had to buy a small reduction in steepness too dearly; especially if the location of this steep slope is not far from the natural place where a relief locomotive is stationed, because the additional use of the relief locomotive on the steep ascent will allow the train to be kept at full load over the rest of the line; which the intermediate slope, negotiated without reinforcement, would not have permitted.

The steepness of ascents negotiated by locomotives in regular service hardly exceeds 0.010 m/m.

Between 0.01 and 0.03 m/m, inclined planes are worked by stationary engines, hauling trains up or holding them back on the descent by means of ropes.

In England, on major operating railways, inclined planes with a slope exceeding 0.027 or 0.028 m/m have hardly been built. — In Belgium, the Liège inclined plane has an inclination

of 0.03 m/m over 1800 meters in length. — The Americans have pushed boldness much further, one might say recklessness: they have, over short lengths it is true, inclined planes of 100 to 200 millimeters per meter — this is trusting a little too much in the solidity of the ropes.

However, ropes on planes of ordinary inclination of 0.01 to 0.03 m/m are not the only safety reason passengers have: if the rope broke, it would be very easy to hold the train back with the help of brakes and prevent it from taking on a dangerous acceleration. Friction of the first kind, or sliding without rotation of iron on iron, is about $^1/_{10}$; it would therefore suffice to stop, by progressively tightening the brakes, the rotation of the wheels of one third of the carriages composing the train to completely neutralize the component of gravity along the slope. Only on a railway which offers such steepness, it is prudent, as can be seen, to include in the composition of trains a high proportion of carriages (from one third to one half) fitted with brakes.

The most commonly used brake arrangements can be seen (figure 16) and particularly (fig. 17), the brake used on the Versailles (Right Bank) and St Germain railway. The use of these various types of brake has the drawback of wearing and de-centering the wheels. For the Liège inclined plane, a system was adopted which, when one wishes to brake, transfers the weight of the carriages, no longer onto the wheels but onto a kind of attached support which comes to rest on the rail (fig. 18). A description of this system can be seen in one of the forthcoming issues of the Annales des ponts et chaussées.

There is little to say about the particular arrangements required by inclined planes worked by stationary engines. It will suffice to indicate the manner of supporting the ropes or of maintaining them at the proper tension, despite the elongations or shortenings which may be the consequence of the stresses they are subjected to or of hygrometric variations.

The ropes pass over pulleys which reduce their friction and prevent them from wearing as quickly as if they were dragged on the ground (fig. 19). These pulleys are placed at a distance of 6 to 8 m; their trunnions have a diameter which varies from 15 to 25 millimeters. The diameter of the pulley should be as large as possible, but the pulleys must touch neither the ground nor the underside of the wagons; this diameter has an upper limit generally equal to 0.40 or 0.45 m. — The ratio $\frac{\delta}{D}$ varies from $\frac{1}{20}$ to $\frac{1}{30}$; the dead weight of each pulley is 25 to 30 kilograms. The weight of rope they support (the diameter of the rope varies from 0.035 to 0.060 m!) is on average 18 to 20 kilograms.

When the inclined plane is a straight line, the pulley is placed vertically in the middle of the track (fig. 20); when it is a curved line, the pulleys are inclined so as to guide the rope in the direction of the curve (fig. 21).

The friction of the pulleys is about $\frac{1}{25^e}$ of the combined weight of the pulley and the rope.

Several means have been employed to maintain the ropes at a suitable degree of tension. We will only indicate the method used on the Liverpool inclined plane.

The ascent of trains is done by means of an endless rope to which they are attached. The movement of this rope is produced by its friction on a system of pulleys or drums, one of which is set in motion by a stationary engine. — (There are almost always two stationary engines, intended to relieve each other, in case of unforeseen stoppage or repairs). — The rope first passes over the upper groove of pulley A, (fig. 22) which has two grooves, embraces more than half the circumference and passes onto the upper part of a two-grooved pulley A', of smaller radius than A, comes to pass around a pulley A'', goes around it, returns to the lower groove of A', then to the lower groove of A, crossing the original direction, and finally returns to the outside to form the second part of the rope that goes down the plane when the other part goes up, or vice versa. – The pulley A'' is not fixed like the others; it is placed on a mobile carriage whose position varies according to the tendency to elongation or shortening of the ropes, and which is held by another suitable weight P placed in an ad hoc point.

Stationary engines generally cost less in maintenance and fuel than locomotives for equal power and for work lasting the same time. But their use has the drawback of requiring a continuous and permanent expenditure for a momentary, occasional use. — In addition, there is always time lost in passing over inclined planes worked by stationary engines; because the train has to be stopped to attach the rope. These are reasons for avoiding the use of inclined planes when circumstances permit without too great sacrifices; the anxiety they generally inspire in passengers is certainly a motive which also carries some weight.

Sometimes it will appear more advantageous to pierce a ridge than to climb it by an inclined plane.

For crossing mountain ranges surrounding basins of a certain order, tunneling will often become an absolute necessity: then the railway is established in a tunnel.

Railway tunnels are usually larger than those built for the establishment of canals; but there is a circumstance which sometimes, despite this, makes the costs of one and the other quite comparable; it is that canal tunnels are almost always, with a view to better ensuring the water supply of the summit level, established below the level of underground waters; whereas railway tunnels must be driven as much as possible above this level. It is understandable that the increased expenditure necessary for dewatering during the construction of the former compensates to a certain extent for the increase in costs resulting from the larger section of the latter.

It must be said, moreover, that the cost of driving a tunnel is far from being proportional, at least as regards the extraction of spoil, to the area of the section given to it. For the numerous tunnels he had executed in beds of limestone rock for the construction of the Marseille canal, Mr. de Montricher found that the driving of the first gallery, whose section was twelve square meters, had resulted in a cost of 18 francs per cubic meter for rock extraction; whereas for the subsequent enlargement of this same gallery, the cost of extraction per cubic meter was only 6 francs.

The blocks or sleepers are never placed directly on the rock bottom in tunnels; the running of trains would be too rough there. Far from it, a greater thickness of ballast would rather be established than on any other part of the track, in order to more completely ensure the drainage of water to a certain depth below the rails. A ballast thickness of 0.60 m is usually reserved.

The chimney of locomotives rises 4 m above the rails.

It can be seen from this that the height of a tunnel for major operation could hardly be less than 6 m to 6.50 m, if one wishes to maintain clear space above above the chimney of the engine. But for ventilation, it is desirable that the space remaining free at the upper part of the tunnel be more considerable. The carbonic gases and sulphurous vapors escaping from the chimney would circulate only with difficulty in such a small space, and after the passage of one or more trains, one could neither breathe nor see in the tunnel. — In the latest projects executed or proposed, tunnels have been given a height of 7.50 m to 8 m. Tunnels are given an almost circular section and a masonry lining in soils which are not very solid and liable to subside due to the action of water. This precaution is indispensable to protect them against lateral and upward thrusts.

In certain tunnels which were made in England without this precaution having been taken, the side walls yielded to the thrust and came together: and the track was found destroyed.

When the length of the tunnel is somewhat great, it becomes necessary to establish ventilation shafts at intervals to clear and freshen it.

On the Birmingham railway, at Kilsby tunnel, whose length is 2,200 m, two shafts were sunk whose base is formed by hemispherical wells 11 meters in diameter. These two shafts divide the length of the tunnel into three parts of 7 to 800 meters; each interval is divided into three equal parts by two shafts of smaller opening at the base. The gigantic shafts of this tunnel are perhaps an excess of precaution; but a certain number of small shafts were, in this case, and would be in all similar cases, necessary.

The construction cost of tunnels is extremely variable: it depends on the nature of the strata to be traversed, their direction, their dislocation, the influx of water, the length of the drives, the height of the shafts to be sunk for the removal of spoil, the more or less frequent necessity that may arise within the tunnel's extent of arching more or less considerable spaces in masonry, etc., etc...

In some cases where an arch is necessary, one may confine oneself to giving it a thickness of one brick or one and a half bricks, as when it is only a question of making a lining to protect schists from the action of air; in other cases, and for example when the ground is clayey, considerable thicknesses must be given to the arch.

A table (fig. 23) can be seen, which was drawn up by Mr. Minard, and which gives the price, length and depth below ground of a certain number of works executed in France or in England.

General layouts.

The preceding indications seem sufficient to guide the detailed studies relating to the choice and distribution of slopes in a railway layout. As regards the general determination of the layout, having regard to the topographical configuration of the ground, the principles relating to this order of considerations are very nearly the same as those we set out with regard to the layout of ordinary roads, in the roads course. Only the necessity of applying these principles is, in the case of railways, more absolute, more rigorous, by reason of the much narrower limits between which the slopes to be adopted can vary.

In general, railways are intended to link together centers of considerable population, commerce or industry. Most usually these large centers will be located on watercourses of the first order. It is therefore almost always between the lower slopes of different basins of the first or second order that railway communications must be established.

To go from one basin to another, watersheds must be crossed. These watersheds should most usually be crossed at the most depressed points of the chain, at the lowest passes among those which do not deviate too much from the direction which, as the crow flies, would be assigned to the line. These passes correspond to the points marked in the direction, extended to the watersheds, of the tributaries of the last order of the basin: the lowest will generally be those indicated by the watercourses penetrating farthest into the chain. There will almost always be a greater or lesser number of solutions among which the choice must be determined not only by views of facility and economy of running costs, but by a set of political and social considerations. Thus, for example, to go from Paris to Lyon, or rather from Paris to Dijon, (the latter town having been considered as an obligatory point of the line of travel) and to pass from the Seine basin into that of the Saône, one can, after following the Seine as far as Montereau, confluence of the Seine and the Yonne, go up one or the other of these two watercourses. In the latter case, leaving the Yonne at the mouth of the Armançon, one arrives at Dijon following very nearly the general layout of the Burgundy canal. If one follows the Seine, arriving at Marsilly-sur-Seine, confluence of the Seine and the Aube, one has to choose between two directions; if one continues to go up the first of the two watercourses, one follows it to its very sources and after crossing the Seine one goes back down to the Saône by the small Ignon valley. If one takes the Aube, one arrives by a longer route at a point on the watershed quite close to the pass chosen in the previous layout and one goes back down to the Saône by the Tille valley. Each of these layouts has, in fact, been proposed. It is understandable that the longest, that of the Aube, was only put forward with a view to complex combinations: in studying this layout, it was considered that it would be possible to make the section between Paris and Arcis or Brienne serve, at least for a more or less long temporary period, the double service of the Paris to Lyon and Paris to Strasbourg railways, these two railways only separating, in this order of ideas, between Arcis and Brienne. Opportunities will frequently arise in which such deviations will be proposed: it is in the very elements of each special question that the reasons for admitting or rejecting such deviations must be sought. We could

not discuss these reasons, even for a determined case, without departing from the subject of this course.

Sometimes deviations of layout will be determined by considerations of a slightly different order: thus, in the Avignon to Marseille layout, the law decided on a lengthening of the journey of twenty-odd kilometers, to touch Arles; not solely, it is understood, with a view to satisfying the demands of a locality, but for the reason that Arles being the point where maritime navigation ceases and river navigation begins, much greater freedom would be left to the various combinations that could be adopted for transports of all kinds taking place in the valley by water or by land, combinations which will have to vary according to the state of the river, than if the railway left the Rhône at a higher point in its course, a point where goods arriving from the lower river or from Mediterranean ports could only arrive after transshipment from coastal vessels to river boats.

We cannot insist on these considerations: it is enough to have indicated them.

In general terms, after having determined the passes from one basin to the other, one must travel from the starting point to this pass by following the tributaries of various orders that lead there by the shortest route. The most important interests will almost always thus be served: that of general circulation and that of local circulation between the most populous centers, these centers being almost always located on watercourses.

As one rises into valleys of lesser importance, steeper slopes will be found; and near the watershed, the gradients may be impossible to negotiate. It is with a view to the difficulties that the watershed must present, that it may be appropriate to rise long in advance on the flanks of the slopes of the last-order valleys by which one reaches these watersheds, in order to distribute the height to be climbed over a longer space. With this precaution, it will be possible in certain particular cases to pass, without a tunnel, from one valley to another belonging to a different basin. When the establishment of a tunnel is necessary, it may be that it is no longer the most depressed pass, but rather the part of the chain where the thickness to be pierced is the smallest, that it is appropriate to choose. However, in almost no case should the height of the watershed above the tunnel level be considered as indifferent, the costs of driving depending to a great extent, as can be concluded from what has been said previously, on this more or less height.

At the entrance and exit of tunnels, the railway is always established in more or less deep cuttings; this is a drawback impossible to escape. But what must be avoided as much as possible, and what is nevertheless not always easy to avoid in railway layouts where one is required to keep so rigorously within narrow limits of slopes and curvatures, is to enter into cuttings that are at all deep on the flanks of hills, especially when the underlying strata are of a clayey nature: considerable damage may result, as has been, not to mention other similar cases, the unfortunate experience on railways executed at the gates of Paris.

A great number of considerations which were developed in the roads course, on the greater or lesser advantages that may be found in placing a layout at a greater or lesser height above the valley floor, and in choosing its exposure in accordance with determined principles, depending on the climate or on the nature of the soil, are to a certain extent applicable to railways. But railways being 25 or 30 times more costly than ordinary roads and consequently only able to be established where the most powerful interests demand them, it is easily understood that considerations which may be preponderant in determining the displacement of a road layout are deemed quite secondary when it comes to a railway. It is necessary, however, while keeping each interest in its order of importance, never to lose sight of, and to sacrifice only as far as may be indispensable, those conditions which are important for the solid and economical establishment of the works of the communication route being planned.

We have had mainly in view in all the preceding, the great lines intended for the general circulation of passengers and goods. There are railways which are established for special operations and whose layout must for that very reason be subject to particular conditions. Such are the railways connecting large mining establishments to general communication routes; and, for example, to rivers and canals: may be cited among others the Saint-Étienne, Rive-de-Gier, Darlington to Stockton, Bolton, etc. railways. — In such a case, it is almost always a question of bringing from a more or less elevated point to some much lower point a considerable mass of bulky products extracted from the mine, and of hauling back, almost empty, the wagons which have served for the descent of these products. Then, when the terrain lends itself to it, slopes steep enough can be adopted so that the trains descend without taking on an excessive increase in speed, under the sole action of gravity, and the hauling back can be done by horses brought down in the wagons with the previous train; or, if the natural slopes of the ground are such that locomotives can advantageously be used, a layout can be determined such that the engines function exerting very nearly the same tractive effort, whether they are hauling loaded wagons on the descent, or empty wagons on the ascent. These are problems which, by means of the indications given previously, will be solved without difficulty in each given case.

When the planes on which the descent and ascent must take place are short enough for such a system to be established, use is made of gravity which pulls the full wagons down, to haul the empty wagons up; it suffices for this to attach the two trains, one placed at the top of the plane, the other placed at the bottom, and on two different tracks, to the ends of a rope coming to wind around a return pulley; (fig. 24). This system constitutes what is called in England the *Self-acting system*; and what is designated in France under the name of *plan automoteur*.

Of the drawbacks and dangers resulting from transition curves and of the means proposed to facilitate the circulation of trains in curves of small radius.

In the haulage carts which circulate on ordinary roads, the wheels are movable around the axles; the rear axle is fixedly united to the body of the carriage, the front axle, on the contrary, is only attached to it by a vertical bolt which passes through it at its center and which is given the name of kingpin; finally, the front wheels are of a fairly small diameter, in order to be able, when turning around the kingpin, to engage more or less into the body of the cart.

According to these arrangements, a 4-wheeled carriage can always be placed on any curve (provided the radius does not become too small) in such a way that the two wheels on the same side being on the curve, each axle is in a direction normal to the curve at the point occupied by the wheel, (fig. 25). If in this situation of the cart, a tractive effort perpendicular to this axle is exerted on the center of the front axle, each outer wheel will describe an element of the curve, and each inner wheel an element of a concentric curve; so that the distances traveled by the centers of the axles will be the same, but the relative length of the elements described by the wheels of the same set will be proportional to the distances between the wheels and the corresponding center of curvature. The tractive effort transmitted to the rear axle by the reach, making with this reach an angle equal to the angle of convergence of the two axles, will tend, during the movement, to maintain the rear axle in a position normal to the curve; and consequently, if, after the traversal of a first element, the tractive force (always directed parallel to the element at the beginning of which the front axle is located) continues to act, the wheels will describe a second element in the same manner; and successively the carriage will traverse the whole curve without anything occurring other than friction (by sliding) on the front axle's skids or rubbing plates, friction of the first kind (by sliding) in the axleboxes and friction of the second kind (by rolling without sliding) on the wheel circumference.

It has been seen for what reasons it was desirable, even under unfavorable conditions for circulation in curves, not to allow curves of too small radius in ordinary roads. But it has also been seen that these curves being naturally very short and usually very few over fairly considerable distances of travel, they did not in general constitute a sufficient obstacle to determine a reduction in load.

Things are quite different on railways: the radii of curves having to be on these tracks much larger than those of ordinary roads, these curves most often have a very extensive development and their ensemble sometimes constitutes a very notable fraction of the length of the line. As, moreover, the increase in traction is very appreciable there, they can become and frequently do become a cause of reduction in speed or load. The increase in traction is due to the harsh frictions exerted, on the upper face of the rails, by the quasi-horizontal part of the tire of some of the wheels, and on the side of the rails, by the flanges which keep the wheels on the rails.

Unlike what happens on ordinary roads, the wheels of carriages or wagons traveling on railways are fixed to the axle; and the wheels of the same set consequently have a linked movement. As, in addition, the axles are maintained in an invariable position with respect to the body of the carriage or wagon, by the collars which house them, the axles of the same carriage remain constantly parallel to each other. It follows from this double arrangement that if the four wheels of a wagon are of the same diameter, they must, in rolling, travel exactly the same path. Now, as on curves the outer wheels must travel more path than the inner wheels, it is therefore necessary that, moment by moment, there be a harsh friction sliding which allows the outer wheels to gain the excess travel they need. This sliding is necessarily determined by the lateral reaction exerted by the rails against the flanges of the front outer wheel and the rear inner wheel; it is, in part, hindered by the action of centrifugal force, and aided by the action of the centripetal force resulting from the obliquity of the traction. It is, moreover, attenuated by the conicity of the wheel tire.

The increase in resistances, the increased wear of wheels and rails which is the consequence thereof, and the danger there could be, if, under the combined action of centrifugal force and the tremor of the rails, the locomotive or some wagon escaped along the tangent by passing over the outer rail, have hitherto determined the general practice of not adopting, in the parts of the railway which must be traversed at high speed, curves below a radius of 500 meters. This condition, coupled with that of the extreme reduction of slopes, creates, in narrow and winding valleys, very great difficulties for the layout and economical execution of railways.

Various means have been proposed to remedy the drawbacks of the linked movement of wheels and the parallelism of axles, and consequently to permit the adoption of curves of smaller radius.

Mr. Laignel, mechanical engineer, proposed to make, in curves, the flange of the outer wheel ride up onto a widened part of the rail, while otherwise maintaining this flange by a raising of the rest of the rail (fig. 26). By this arrangement, if the inner wheel of an isolated axle describes a curve of radius $\overline{R}$, l being the track width, r the wheel radius and h the flange height, the outer wheel naturally describes by rotation without sliding a circle whose radius is $l + R = l + \frac{r.l}{h}$; — and the radius that all curves on the same layout must have is constant and equal, if measured from the middle of the track, to $\frac{l}{2} + \frac{rl}{h}$.

This system is ingenious and it offers this particular advantage that at the same time as it remedies to a certain extent, the fixity of wheels on axles, it creates by the raising of the outer wheel a transverse component of gravity which more or less counterbalances the action of centrifugal force. — It is already known that the raising of the rail is accepted in usual railway practice to produce a similar effect. But there are objections to the general use of this system which seem to present gravity.

It must be noted first that the parallelism of axles not being destroyed and always preventing each of the axles of the same carriage from having the center of rotation that would suit it, Mr. Laignel's combination destroys only one of the two drawbacks produced by the current mode of construction of locomotives and wagons. If sliding had not manifested itself in a marked way (and it does not seem that this was the case) in the experiments that this mechanic partly carried out, it could only have been because he had left the axles of the roughly constructed cart he used in these experiments enough play in the boxes for them to be able to take convergent positions; and it is quite clear that such an arrangement would present formidable dangers in their application to wagons circulating on high-speed railways.

Secondly, the invariability of the curve radius is a real drawback: undoubtedly, it is always possible to form curves composed of a series of circular parts and straight portions whose general shape does not deviate too much from the layout determined by a continuous circle of any radius. However, it is understandable that this does not allow one to follow the sinuous contours of narrow valleys as much as would be necessary to escape the necessity of large earth movements.

Thirdly, the raising that would suit the outer wheel of the locomotive is not the same as that necessary for the outer wheels of the wagons for the description of the circle of the same radius. All the wheels of the train should have the same diameter and the same flange height.

Fourthly, the circle which would be described by an isolated axle by virtue of rolling on the flange would be, by reason of the dimensions currently attributed to wheels, track and flanges, about 35 m; by reason of the parallelism of axles, the circle naturally described under the same conditions by a 4-wheeled wagon would, without doubt, be 70 to 80 m. It is very doubtful that one would venture to traverse such curves in daily service at very high speeds, and yet in the proposed system these curvatures could not be increased in suitable proportions (to 150 or 200 m) without reducing the height of the flanges or increasing the diameter of the wheels more than is possible.

For these reasons, it does not seem that Mr. Laignel's system can be advantageously used on the parts of the railway traversed at high speed; but, it is certain that it can be very useful (especially because it requires no modification of the rolling stock) in depots and generally on all secondary service tracks.

Mr. Arnoux, a former student of the École Polytechnique and administrator of the Messageries Lafitte et Caillard, has proposed a system which restores to wheels their mobility around axles and ensures for axles the convergence suitable to them according to the curve radius. He has done more: he has spent considerable sums to make a large-scale trial of this system with a locomotive and carriages built ad hoc, on a railway established for this purpose at Saint-Mandé, forming a closed circuit and laid out so as to present slopes and levels as well as straight parts and curved parts of various radii, and even a portion of a circle of 50 meters radius. Numerous experiments carried out at a speed of 10 leagues per hour have

demonstrated that the combinations devised by Mr. Arnoux were truly worthy of the attention of engineers.

According to this system, each carriage is composed of a front undercarriage and a rear undercarriage. In each undercarriage the axle is traversed by a kingpin around which it can turn. A horizontal ring is attached to it on the same axis as the kingpin. The wheels are free on the axles.

The two undercarriages are united by a branched reach, at the ends of which are attached, underneath, plates concentric with the kingpins and which turn with easy friction on the rings. The rings, being integral with the axles of the two undercarriages, have the same diameter.

Chains attached to the circumference of the rings, so as to cross under the reach, unite these two axles and oblige them to move simultaneously and in opposite directions around the kingpins, forming with their original directions respectively angles of the same value, equal to half the angle of convergence.

The carriages are linked to each other:

1° by a drawbar traversed by the kingpin of the rear undercarriage of the preceding carriage, and by that of the front undercarriage of the following one;

2° by two chains which cross under the drawbar and which are attached, at one end, to the circumference of the ring of the front undercarriage of the second carriage, and at the other end, to the circumference of a ring of suitably determined radius, fixed to the reach of the first carriage and traversed by the kingpin of the rear undercarriage.

Thus there are three horizontal rings on each carriage: two of the same radius are fixed to the axles and another, of a generally different radius, is integral with the reach at the rear undercarriage.

It results from this latter arrangement that the reach of the first carriage cannot change direction without at the same time producing a change in the direction of the axles of the second carriage; and, by suitably determining the radius of the small ring, the axles of the second carriage will be, like those of the first, normal to the curve that the two carriages are traversing.

Suppose that the drawbars of the carriages are equal to the reaches, as was found to be the case for most of the carriages put into experiment by Mr. Arnoux, on the Saint-Mandé test track; the rings integral with the reach at the rear undercarriages of the carriages would have to be of a radius half that of the axle rings.

Let, in fact, *AB* be the reach of the first carriage, *BC* the position that the drawbar of the second will take on the curve *ABC*, intermediate between that of the two rails; the angle

formed by the line *AB* and the extension *BK* of line *BC* is double that which each of these lines forms with the tangent to the circle at point *B*.

Now, *e′e′* the position of the first axle of the second carriage having to converge towards the center, and be normal to the circumference *ABC*, at point *C*, will make with its former position *ee* perpendicular to *CB″* an angle half of *BCB″*, which angle *BCB″* = the angle *KBA* through which the reach of the first carriage has turned relative to the drawbar of the second.

It is therefore necessary, to make the first axle of the second carriage normal to the curve, to impart to these axles an angular movement half of the relative angular movement of the reach and the drawbar; and it suffices for this to attach, as stated, to the reach of the 1st carriage, at the rear undercarriage, a ring of a radius equal to half the radius of the ring of the front undercarriage of the following carriage, and to make the movements of these rings interdependent by crossed Vaucanson chains.

To complete the system, by giving the direction of convergence to the first axle of the first carriage, four rollers movable around vertical axes and placed in pairs at the ends of iron forks placed under the front axle of the engine come to bear by their groove against the inner faces of the rails and keep this first axle in a position constantly perpendicular to the rails.

These combinations are certainly very ingenious and easy to apply. Nevertheless, they present serious drawbacks which we will enumerate:

1° All the wheels are interdependent: therefore, when a train is half out of a curve, or half entered, the action of the communication chains tending to bring the axles of the rear carriages into the relative position suitable for the curvature of the point where the front ones are, there will be considerable lateral friction. But this is only an evil that is felt for very short times.

2° A much longer time is needed than in the current system to increase or decrease the number of carriages composing a train.

3° A train can only run in one direction, firstly because there are guide rollers only at the front, and secondly because to change direction the movement communications via the rings would also have to be changed, which would have to be placed in reverse order. It is therefore not possible to reverse.

4° In depots and on service tracks, it constantly happens that a carriage must be moved forward or backward to separate it from a train or to join it to one; these isolated carriages will no longer have anything to guide their axles, and consequently they cannot be directed and kept on the rails.

5° The system moving, as it were, all in one piece, the force of inertia it will oppose to starting may be considerable enough for the driving wheels to slip on the rails. In the current arrangement, the carriages can move apart and come closer together more or less, thanks to the flexibility of the chains and springs that

unite them. In general, at the moment of departure, the chains are slack: the result is that the tractive force of the engine only attacks the second carriage after having set the first in motion; the 3rd only after having hauled the two preceding ones, and so on successively.

In the Arnoux system, on the contrary, the whole mass must be set in motion by a single effort: and it will frequently happen that this effort exceeds the limits of the adhesion force.

6° The wheels are movable around the axle journals, which leads to giving these journals a much larger diameter than that which is adapted for the trunnions of axles of current carriages, and which consequently very notably increases the work of friction. This drawback is very serious, since it leads to this direct consequence that to mitigate the drawbacks of curves which in general form only the lesser part of the length of a railway, the tractive effort of the engine over the rest of the line is increased to a large extent.

This is not only a theoretical forecast. By applying the said stylus manometer to the engine, in experiments carried out at Saint-Mandé, it was found that the average effort exerted by the locomotive hauling five carriages of total weight 17,049 kg had been 130 kilograms; now, by separately evaluating the influence of slopes, it is deduced from this result that the effort exerted on the curve, assumed horizontal, was about 5.6 kg per ton. This is an effort double that which results from the use of ordinary wagons on a straight line on horizontal ground. Undoubtedly, it is possible that the small-radius curves contained in the Saint-Mandé test track contributed to raising the traction figures; but it will be impossible not to attribute the largest part of this increase in effort to the increase in the diameter of the journals: a drawback which seems inherent to the system and which appears to us to present a very high gravity.

If these objections are weighed, and particularly the third and the last, one will think, no doubt, that the Arnoux system, despite its incontestable merit, will not be susceptible to application in ordinary service, until it has received notable improvements.

In the following system (Wilback system) a false axle which passes through the kingpin of each undercarriage of a carriage supports two half-axles to which the wheels are fixed, (fig. 26). Thus both these conditions are realized simultaneously: mobility around a vertical axis, linking of wheels to their axles.

To determine convergence, two rods, one fixed to the front undercarriage axle, the other to the rear undercarriage axle, come to mesh with a toothed wheel on a vertical axis. The movement of this wheel, in one direction or the other, brings together or separates the points A and A' of attachment of the two rods on the axles, and forces the axles to form the same angle with their original directions.

The movement is given to this wheel by means of a bevel pinion whose crank projects outside the lateral plane of the carriages. Pushers which raise or lower the crank to the appropriate degree are placed at the beginning and end of each curve and determine the movement. The spring which bears on the gearing does not allow the axles to move under any other influence than that of the pusher.

The use of these pushers presents a serious drawback: it necessitates a shock which must be avoided with extreme care in circumstances involving enormous masses moved at high speed. The gears would be incessantly broken. This dangerous means can moreover be ineffective because it is possible that the crank may not reach the pusher, during some of those oscillatory movements hitherto so common in railway locomotion.

If this system were perfected enough to become of usual employment, it would have over the previous one the great advantage of being able to be applied to all or part of a line, without requiring the almost complete reconstruction of all the rolling stock.

Several others have been presented, among which may be cited those of Messrs. Chesneaux and Verrier. But there is no point in discussing at present the merit of these various systems, which have all remained in the project stage.

Establishment of the track.

There are several essential things to consider in questions relating to the establishment of the track; namely:

1° The track gauge;

2° The method of track establishment;

3° The spacing of supports and the dimensions of rails;

4° The shape of the rail and fastening systems.

We will examine these different questions successively.

1° Track gauge.

In railways built up to now in France (at least in those of some importance) the distance between the rails has been fixed at 1.50 m center to center, or 1.44 m between the inner edges of the rails.

The economy for commerce resulting from transports carried out without transshipment over a very great length of journey now almost makes it a necessity to adopt this same track gauge for all railways which are to be placed in direct communication with railways already built.

The importance of this consideration will be understood if it is noted that at each point where packages have to be changed from one carriage to another, there are costs to bear for the maintenance of supervising agents, cartage costs from one carriage to another and costs for putting barrels, casks, cloth, etc., which wrap or enclose the goods and which necessarily suffer damage in the frequent handling of the transported objects.

These expenses, which sometimes are not sufficiently taken into account, are of such importance that on long water transport lines, the total transport price, having regard to these additional costs, can become equal and even higher (tolls being included in the evaluation neither at departure nor otherwise) than the price of transport carried out without transshipment by rail.

This reason for giving the same track gauge to the whole line of a network is a determining consideration for keeping the 1.50 m gauge adopted so far.

And yet it is perhaps regrettable that a too restricted gauge was originally adopted, which, by obliging the parts of the locomotive mechanism to be squeezed into too narrow a space, becomes one of the main causes of the enormous repair costs of engines in which one finds oneself involved. These expenses, in fact, constitute a very large part of the overheads and absorb a considerable portion of the gross receipts from tolls collected.

Now all English mechanical engineers agree on this point, that by giving a little more width to the track, increasing it by 15 to 16 centimeters, one could manage to give these parts enough strength and enough play to result in very important savings in repair costs.

The increase in gauge would have another advantage: that of presenting more stability for carriages, whose wheels would be farther apart; consequently allowing the diameter of these wheels to be increased without diminishing stability on the track; and consequently increasing speed, without multiplying beyond all limit the number of piston oscillations.

The London to Bristol railway has a gauge of 2.20 m and driving wheels of 7 or 8 English feet. Thus an ordinary average speed of 10 to 12 leagues per hour is obtained there without effort.

It is permissible to think that the track gauge of the Bristol railway is exaggerated, because it entails as a necessary consequence too great a reinforcement of axles, too great an increase in the weight of carriages, and consequently a very costly increase in the weight of rails. It also requires a notable increase in the radius of curves.

But, perhaps there would be, without falling into this exaggeration, some advantages in conceding the increase in track gauge that engine builders demand.

Moreover, this change could be made without any notable modification being required in the dimensions currently adopted for the construction of the railway.

It would suffice to take the 15 centimeters that would be given extra to each track, from the width currently attributed to the space between tracks, which would be reduced from 1.80 m to 1.50 m.

The only difficulty that could oppose the adoption of such a change would result from the very great importance of the expenses to be incurred for the change of the rolling stock; but this difficulty is serious and perhaps the progress made day by day in the construction of engines will lead to solving the problem of rapid, safe, and economical transport by the improvement of locomotive mechanism before a sufficient interest is found in the increase of the gauge to incur the expenses which a change in track gauge would not fail to entail.

2° Method of track establishment.

Rails must maintain their height, their parallelism and their level at the joint, essential conditions for rolling and in which it is all the more difficult to maintain them as the vehicles have more mass and speed.

Rails were first laid on stone blocks 0.30 m square and 0.20 m thick, spaced 90 cm center to center. It was soon noticed that blocks of these dimensions did not have a sufficient seating on the ground; and the superficial dimensions of the block were increased to 0.60 m by 0.60 m, and the thickness to 0.30 m. Despite this modification, the blocks, having between them only the solidarity that could result from their connection by the supported rails, continued to tilt either in the direction of the rail or laterally so as to determine undulations of the rail in elevation and in plan. If the undulations had been the same on the two lines of rails composing the track, the drawback would already have been very serious; but the two lines, not being interdependent, were more likely to undergo inverse effects than similar and simultaneous effects; consequently, the track gauge could be seriously modified and have as a consequence either considerable increases in lateral friction, or dangers of derailment. To remedy in part this lack of solidarity of the blocks of the same line, it was proposed to bind these blocks together by cemented masonry; but the continual tremors occasioned by the passage of trains would soon disaggregate the masonry masses, mortars not being capable of adapting to all these movements without losing the cementing faculty proper to them. What it was important to find was a body to interpose between the rails and the ground, which would satisfy at the same time these conditions: to present a sufficient seating on the ground, to establish as much solidarity as possible between the two lines of rails and to offer such rigidity and elasticity that without giving rise to harsh shocks, it would firmly oppose too marked depressions. Wood perfectly satisfied all these conditions: so despite the drawback it presents of being subject to rot more or less quickly and consequently requiring more or less frequent and more or less costly replacements, it is now preferred by the generality of railway builders. Wood has been used in the form of sleepers connecting the two lines (fig. 28). This is the most commonly used system; it has also been used in the form of longitudinal timbers continuously supporting the

rail of each line, the spacing of these longitudinal timbers being otherwise maintained at intervals by transverse pieces of wood or cast iron, and by iron tie rods. This is the mode originally preferred in America (fig. 29). In this latter system, it is necessary, in our opinion, to consider the assembly of longitudinal timbers and crosspieces as constituting the resistant part of the track, and the iron strip superimposed on the inner edge of the longitudinal timbers as having no other object than to reduce the resistance to rolling to the figure corresponding to iron rolling on iron. It is understandable that in a country covered with forests, where wood was very cheap and iron at a relatively very high rate, such a system must have presented very great advantages. It is likely that in certain localities in our European countries, this mode could also be very usefully employed. Perhaps this system was abandoned a little too hastily, in favor of adopting everywhere arrangements which necessarily lead to much higher expenses.

On the London to Bristol railway where, from the beginning, many novelties were introduced, longitudinal timbers, crosspieces and transverse iron tie rods were adopted at the same time, together with a rail of particular shape (fig. 30), whose section was not less than that of rails usually employed on railways where there are no longitudinal timbers. In addition, it had been deemed appropriate to rest the longitudinal timbers on the heads of piles placed at intervals and completely embedded in the ground. This trial of piling was not successful: each pile head constituting a more resistant point than any other point on the longitudinal timber line, a vertical oscillation from one pile head to another formed under the passage of trains, and the continuity and regularity of these oscillations produced on travelers an effect of indefinable discomfort very similar to seasickness. These piles had to be removed. — It may also be thought that there is prodigality in the simultaneous use of strong longitudinal timbers and rails of high weight: it does not seem that the builder of this railway, who is nevertheless a distinguished engineer, sufficiently accounted for the particular action he intended to obtain from each of the parts of his system. It seems that he should either not have put longitudinal timbers or have notably reduced the weight of the iron.

Today, the almost exclusively employed mode of track establishment is that which was described when dealing with the Orléans railway: this mode consists of taking rails of such a section that they can support, without taking too great a deflection, the weight of the vehicles which must circulate on the track, of connecting the two lines of rail constituting the track by wooden sleepers offering a sufficient seating, and of resting these sleepers on a thick layer of sand which further distributes, by virtue of the properties proper to this substance, the pressure supported by these sleepers over a larger area of the underlying ground.

3° Of the spacing of supports and the weight of rails.

Since the establishment of the Liverpool railway, a perhaps unfortunate tendency has manifested itself, at the same time as the weight of locomotives was increasingly increased, to

progressively increase the spacing of sleepers and the weight of rails. Thus the length of the rail of 15 English feet (4.50 m) which had been divided on the Liverpool railway into five intervals of 3 feet each (0.91 m) was divided, during the construction of the London to Birmingham railway, into only four intervals, and the weight was increased from 55 to 70 English pounds. But it was soon recognized on this latter railway that despite the increase in the weight of rails and having regard to the corresponding increase in the weight of engines, the spacing of 1.12 m was too great; and the division into five was restored over the greater part of the line.

Under a weight at rest, the deflections that pieces supported or built into supports can take are directly proportional to the cubes of the support spacings and inversely proportional to the cubes of the heights and to the first power of the widths of the pieces. In the case where the width of the pieces remained the same, to have only the same deflections, the heights and consequently the weights would therefore have to increase in the same ratio as the support spacings. In the case where the width would not be the same, and if, for example, it were admitted that the sections were similar figures, the weight would have to increase in a ratio of 4 to 5; it is in the ratio of 9 to 10 that the section, and consequently the weight of the pieces, would vary. If one calculates on these bases, and starting from known prices, the cost price per linear meter of the iron track, under the double hypothesis of division into four and five intervals, it will be seen that there is an economy of construction in preferring division into five.

This assessment assumes that no greater deflections should be allowed for one spacing than for another; this assumption is based on the fact that the motion of the train becomes the less agreeable to travelers, determines effects the more prejudicial to the economical maintenance of the railway and locomotives, and requires an all the greater tractive effort as the vertical oscillations are stronger: it is therefore necessary not to allow these oscillations to develop beyond certain determined limits. This is what is assumed in the preceding summary assessment.

The length of the rail (4.50 m) should not be divided into equal intervals. The whole difference in resistance presented by a solid simply placed on two supports or completely built in is known. For railway rails, no part can be considered as absolutely built in or as simply placed on supports; but it is beyond doubt that the middle parts of each length of rail are in conditions much more comparable to those constituting built-in ends than the end parts: it is therefore appropriate to decrease the spacing length of the supports as one moves away from the middle. Lengths of 0.70 - 1.00 - 1.10 - 1.00 - 0.70 m would seem very likely to be advantageously adopted for the five rail lengths.

4° Shape of rails.

After having dealt briefly with the method of track establishment, the track gauge and the spacing of supports, it remains for us to review the different shapes of rails and the various fastening systems that can be used in a railway.

The first rails that were used, mainly for goods transport, were made of cast iron, composed of a flat horizontal part 0.09 m wide and 0.02 m thick, with a vertical top flange 0.04 m high (fig. 31), and sometimes also with a bottom vertical rib having 0.07 m projection in the middle and tapering off at the ends (fig. 32). The horizontal part carried the wheel, the top flange prevented it from leaving the rail, finally the vertical part underneath had no other purpose than to strengthen the first.

These rails were fixed onto wooden longitudinal timbers by countersunk nails; or else they were fixed onto stone blocks with iron spikes which were driven into wooden plugs previously placed in the blocks.

This shape of rail has now been abandoned; because it favors the retention of dust, mud, and water in the groove; this increases friction and hastens the deterioration of the cast iron; moreover, the fastening system by means of nails offers serious drawbacks: temperature changes cause pulling on the nail heads which are soon broken off unless the rail bends; and when this rail takes a slight deflection under the load of a carriage, the nail tends first to rise, but is soon flattened by the passage of the wheel: these opposing movements end up breaking the head of the spike, and the rail has no more solidity. The same drawback still occurs on American railways which are composed of longitudinal timbers onto which the rails are nailed.

After having renounced this system, rails were adopted whose section was in the form of a T (fig. 33) and which on their length presented underneath the shape of solids of equal resistance (fig. 34). But cast iron rails were soon abandoned for high-speed railways and replaced by rolled iron rails which offer numerous advantages over the former.

1° Cast iron rails break frequently and suddenly.

2° They can only be given a length equal to the distance between two supports, because cast iron being not very flexible, it would be impossible to make these rails bear solidly on more than two blocks at once: now, each rail end having only a very short length, vertical undulations and all the drawbacks which are the consequences thereof were disproportionately multiplied on these tracks.

3° Cast iron rails offering a fairly great hardness at their surface, but over a small thickness, when this was worn, the part it covered resisted very unevenly and soon became rough and jolting, resulting in increased traction and dislocation of the track.

These reasons and several others led to the adoption of rolled iron rails. For some time, although having changed the material used, the length and the rail fastening system, the

shape of a beam of equal resistance, the so-called fish-belly shape, continued to be given to the underside of the rail. But this shape was soon also abandoned, as it created constraints in manufacturing and laying and, far from strengthening the rail, placed it in unfavorable conditions of resistance; from the moment it was no longer a question of separate solids resting individually from block to block, but rather of continuous pieces which could be considered as very nearly built in on the sleepers. It is known, in fact, that it is not only in the middle of the intervals, but also at the points of fixing that built-in pieces tend mainly to break.

The form first adopted was that of a *T*, the vertical part having the aim of giving more strength, then a certain quantity of material was accumulated at the extremity to make the extreme fibers, which most effectively oppose bending, play a greater role. By passing through successive modifications, (fig. 35) the double T shape now generally adopted was arrived at. The inner projection of the upper part of the rail having a tendency to separate from the vertical part, buttresses are generally placed to connect these two parts; the salient angles are also removed and a shape is thus arrived at which differs very little from that indicated (fig. 36). One of the great advantages of the double T shape is that the rail can be placed in four directions with respect to the wheel flange; this necessity of successively presenting the different parts of the rail to the wheel flange does not arise because the rail wears from rolling; for this wear is invisible, nor because the rail oxidizes since this oxidation does not occur during circulation, but because in certain rails longitudinal cracks form on the edge which often extend very far. These drawbacks can be prevented to a certain extent by giving the rail a slight convexity in the transverse direction.

In England, on the Bristol railway, a system of rails having the shape indicated (fig. 37) and fixed by countersunk nails was tried. This system does not seem to present any real advantage and has some drawbacks arising from the nails that fix them.

Fastening system.

We have seen that in the old grooved rail system, the rails were fixed by means of nails, which gave very poor results. As soon as raised rails were adopted, they were terminated by kinds of lugs which rested on the stone blocks where they were fixed by spikes; in this system, the rails were juxtaposed end to end. The load ultimately bore on the four ends of the lugs (fig. 38); and so that the upper surfaces of three consecutive blocks would not be in the same plane, the lugs overhung and the rigidity of the cast iron not allowing the system to bend, the lugs which immediately received the action of the wagons often broke.

The idea came to interpose a third body between the rail and the block, in order to attenuate part of the shock, and the rails were made to rest on the block by means of a cast iron piece called a chair.

These chairs were fixed to the blocks by two spikes and the end of each rail resting on the chair was also traversed by a horizontal bolt passing through the two jaws of the chair (fig. 39). It is noted that the blocks, which sink more or less under the weight of the carriages, tilted forwards or backwards during the passage of the wagons which passed over them, that then the end of one rail was raised while that of the adjacent rail was lowered (fig. 40), resulting in a sudden projection on the upper surface of the railway and a shock harmful to the rails, to the wagon wheels and to the motive power.

To diminish this drawback, rails were joined with a half-lap, cutting and crossing them for about 0.06 m. The chair was no longer traversed except by a single horizontal bolt which passed through the joint of the two rails; moreover, by cutting off the angles of the horizontal part on which the rails rest and giving it a convex form, the chair presented only a vertical point of support underneath the middle of the joint. By this arrangement, each rail rested on this summit, and the block could tilt forwards or backwards without the support point changing very noticeably, or at least the two rails descended together. This system presented drawbacks due to the pulling of the bolt by the longitudinal expansion or contraction of the rails.

Attempts were then made to connect the rails to the chairs by means other than bolts. A reinforcement was provided in one of the jaws of the chair into which a raised part of the rail is inserted laterally; to press the rail against the chair which it touches only by one jaw, a wedge of wood or iron is driven between the other jaw and the rail; it is introduced horizontally and parallel to the length of the rail into a small notch made in the jaw of the chairs to give entry.

On the Liverpool railway this system was used with 2 iron wedges; by driving these wedges in, the jaw of the chair can be made to split; this is a drawback not presented by the wooden wedges used on the Roanne and Denain railways. But on these latter railways the rail had been made to touch the chair at quite a large number of points; and it was given a very great height outside the chair, from which said position, which required contact at several points, resulted difficulties in laying, and something variable in the position of the rail; from the great height of the rail above the chair, an unfortunate tendency to tilt, a lack of solidity.

On the Leeds and Selby railway, the rail, except the upper part, was entirely engaged in the chair; it rests on the jaw only at two points, and it is pressed by a wooden wedge of a somewhat contorted shape (fig. 41).

Finally in the current system, wooden wedges are used which support the rail very close to the head and which do not present the contorted shapes of the Selby rail (fig. 42).

The wedges have been placed successively on the inside and outside of the track. When they are on the outside, the action of the wagons, which always push the rails to this side, is transmitted less abruptly to the chair, and the upper part A of the chair (fig. 43) is overhung by the projection of the rail and thus escapes the wheel flange. This also allows the wedges to

be covered with sand and to protect them somewhat from atmospheric influences which would dry them out, increase their play and make their destruction more rapid.

5° Succinct indications concerning the drafting of projects.

General principles were previously given on the construction of engineering structures, whatever the means of communication for which they are intended. In the presentation on the Orléans railway, special indications were given on the particular conditions that engineering structures to be built for the establishment of railways must satisfy. We will add here only two or three summary observations.

Bridges built under railways should in general be built in masonry, unless serious difficulties oppose it; there is all the more reason to adhere to this recommendation as the bridges must have a greater span. The conditions of elasticity presented by wood and iron are not in this case favorable; and moreover, there are reasons of another nature which also tend to reject their use.

Suspension bridges are too mobile for the enormous masses composing a train to be loaded upon them with impunity. One or two trials of this mode of construction have been made which were not successful; the floors had to be supported afterwards by frames or centers built underneath. This was a result that could have been predicted without difficulty.

Even supposing that these bridges had offered sufficient direct resistance at the time of their execution, it would have been feared that the continuity of vibrations resulting from the passage of trains would progressively alter the texture of the wires composing the cables or of the bars composing the chains; and that in a fairly short space of time, the passage of trains could not take place without danger.

This observation does not apply only, it is understood, to the irons used in suspension bridges; it applies generally to irons and cast irons used in any way for the establishment of spans under railways; however, when it is a question of crossing very small openings for which girders presenting a great excess of resistance can easily be used, it will be good, in many cases, to use cast iron: what it will be prudent to refrain from is to build, without well-established necessity, large cast iron bridges, until more complete experience has been acquired on the importance of the effects that ordinary railway operation must produce on this type of structure.

As for timber bridges, they have against them both the frequent repairs they may give rise to, and the rapid destruction to which their assemblies, constantly set in motion by enormous loads, are exposed. If it were necessary to build them, it would be appropriate to admit only pieces with plane sections, without tenons or mortises, and resting on suitably arranged cast iron base plates or sockets.

To these summary observations, it seems useful to us to add some indications on the amount of expenses usually required for the acquisitions and works indispensable for the establishment of a railway.(*)

These indications, which may allow an initial appreciation, by way of comparison, of the greater or lesser importance of the sums to be spent for the execution of a preliminary project, relate to the extent of the land zone to be acquired, to the volume and average price of earthworks per linear meter, to the average price per Kilometer of ordinary engineering structures, to the price of tunnels and to the price of operating equipment; all deduced from results observed on a certain number of railways built so far.

Average width of lands to be acquired for the establishment of a railway.

The average width of lands to be acquired for the establishment of railways in somewhat uneven countries can be estimated at 35 to 40 meters. This width, which at first glance may seem exaggerated, is necessary for several reasons, the main ones being:

1° The footing of slopes required by cuttings and embankments, often considerable, of a railway.

2° The deposits and borrow pits of earth that are frequently obliged to be made near the railway to avoid too long transports.

3° Lateral roads, 3, 4, 5 and sometimes 6 m wide, which inhabitants rightly demand, and which inquiry commissions readily admit, for the restoration of intercepted communications and for the service of properties cut by the railway.

4° The lateral ditches indispensable for restoring the course of waters, modified by the construction of the railway.

5° The sidings and standing depots and their appurtenances.

In a summary table of the areas of land acquired for the Orléans railway, it can be seen that the average width is in fact 40.61 m.

A note emanating from Mr. Talabot estimates at 44.40 m the average width of lands purchased for the Alais to Beaucaire railway.

For the Rouen railway, 430 hectares were purchased for a length of 127 Kilometers: the average width is consequently 33.80 m. This area does not include the depots, at least the main ones.

(*) These indications are taken from a report read to the Council of Bridges and Roads by Mr. Divisional Inspector Mallet, on behalf of a Commission composed of MM. Fèvre, Kemmangant, Minard, Silguy and Mallet, Rapporteur.

Volume and average price of earthworks per linear meter.

The volume of earthworks for the Rouen railway is 3,188,399 m³ for a distance of 122,324 m. These two figures give per linear meter . . . . . 25.50 m³.

On the Orléans railway this volume is . . . . . 33.00 m³.

It is 22.00 m³ on the Montpellier to Nîmes railway.

On the Orléans railway the average price per cubic meter of earthworks was 1.50 francs; on the Rouen railway, it is 1.68 francs; it appears likely to be 1.45 francs on the Montpellier to Nîmes railway.

Average price of engineering structures per Kilometer.

On the Orléans railway, over a length of 133 km, the structures number 221, not counting the passage of the outer Boulevard in Paris, which cost . . . . . 205,000 francs.

The Choisy crossing . . . . . 160,000 francs.

The Orge viaduct . . . . . 250,000 francs.

The Yvette viaduct . . . . . 100,000 francs.

Two viaducts at Étampes . . . . . 220,000 francs.

6 — having cost . . . . . **935,000 francs**.

The expense to which the 221 ordinary engineering structures gave rise is **3,765,000 francs**.

On the Rouen railway, over a length of 127 km measured from its junction with the Saint-Germain railway to Rouen, there are 221 engineering structures, not counting four large bridges over the Seine which cost about . . . . . 2,900,000 francs.

These 221 structures cost . . . . . 3,220,000 francs.

The Montpellier to Nîmes railway, over a length of 50,000 m, presents 98 engineering structures (not counting the Nîmes viaduct), which will cost . . . . . 1,600,000 francs.

The average price of each ordinary engineering structure will consequently be, on the Orléans railway . . . . . .17,056 francs.

On the Rouen railway . . . . . 14,570 francs.

And on the Montpellier to Nîmes railway . . . . . 16,300 francs.

There will be per league of 4,000 m, on the Orléans railway 6.65 ordinary engineering structures, costing . . . . . 113,000 francs.

On the Rouen railway, 6.95 ordinary engineering structures at the price of 101,000 francs.

Engineering structures on the Montpellier to Nîmes railway number 7.44 per league and will cost . . . . . 128,000 francs.

Price of tunnels.

The price of tunnels varies within very wide limits.

The Saint-Quentin tunnels in France and the Medway tunnel in England cost only 700 to 800 francs per linear meter, while that of Pouilly cost 2,000 francs; that of La Coloncelle 3,000 francs and that of Saint-Cloud 2,180 francs. In England, those of Liverpool (the third), Clay-Cross, Kilsby and Box, cost per linear meter 2,220 francs — 2,780 francs — 3,400 francs — and 2,500 francs.

The tunnels of the Paris to Rouen Railway, whose total length is 5,106 meters, were awarded at a price of 1104.57 francs per linear meter. In most, as expected, only fairly soft limestone beds were found, separated by siliceous layers; but, at Rolleboise, the longest of all (it is 2600 m long), this homogeneity of the ground was disproved, and a kind of conglomerate composed of siliceous pebbles embedded in a very hard calcareous gangue was encountered over 600 m in length, and this over an entire section of the gallery. Hence an increase in expenditure of 1000 francs per linear meter; so that the Rolleboise tunnel cost, by distributing this extra cost over the whole length, 1335 francs instead of 1104.57 francs.

Price of operating equipment.

The rolling stock of the London to Birmingham railway, whose length is 480.5 km(*), has a value of 8,400,000 francs, i.e., per Km. 46,500 fr.

That of the London to Southampton railway is, for a length of 123 km, 5,000,000 francs, i.e., per Kilometer . . . . . 40,650 fr.

That of the Grand Junction railway for a length of 133 km is 5,400,000 francs, i.e., per Kilometer . . . . . 40,600 fr.

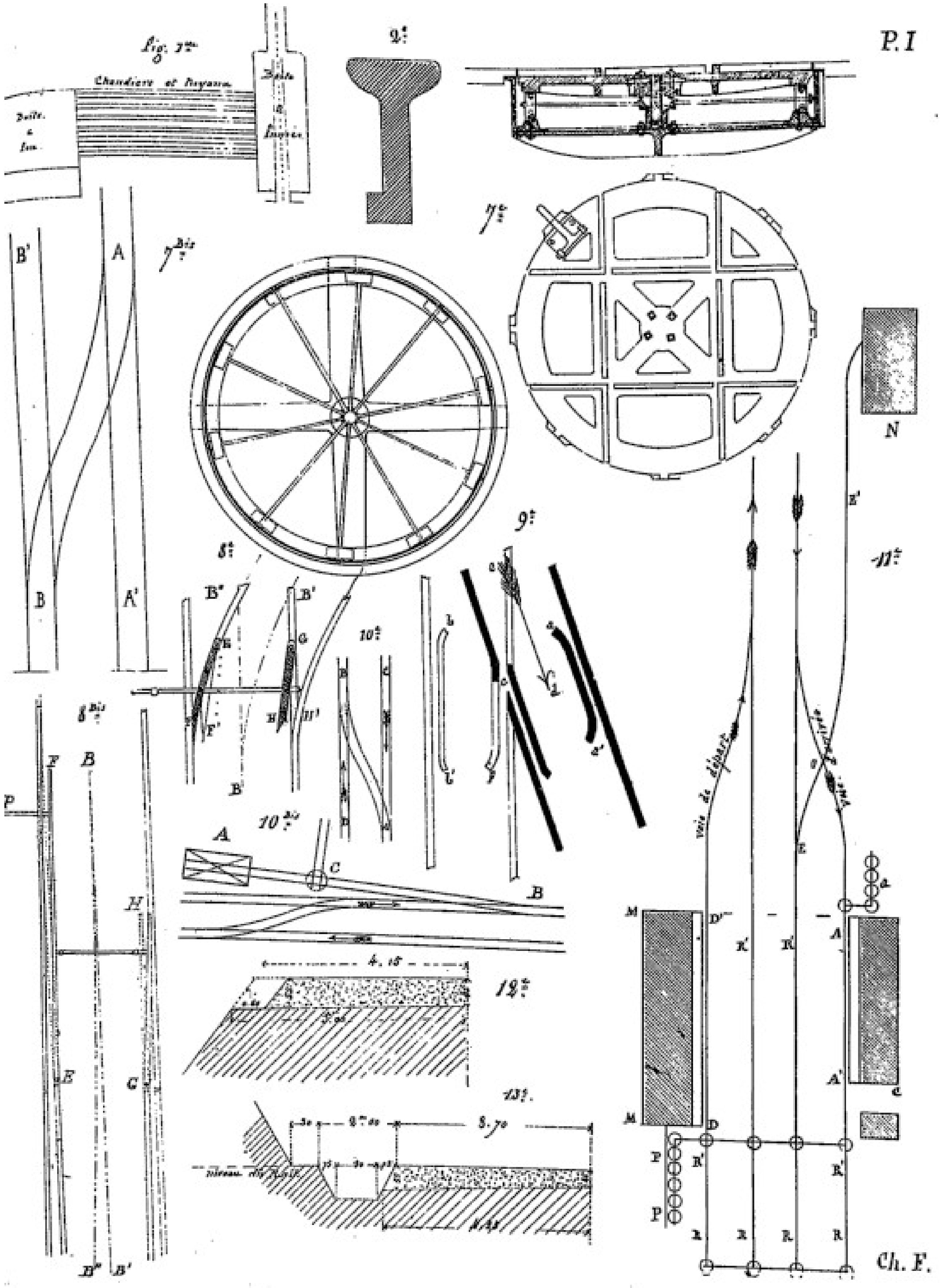
The equipment of the Orléans railway is for 133 km, 4,700,000 francs, i.e., per Kilometer . . . . . 36,340 fr.

Finally, that of the Belgian railway is, for a length of 561 Kilometers, 20,600,000 francs, i.e., per kilometer . . . . . 38,148 fr.

Total . . . . . 202,238 fr

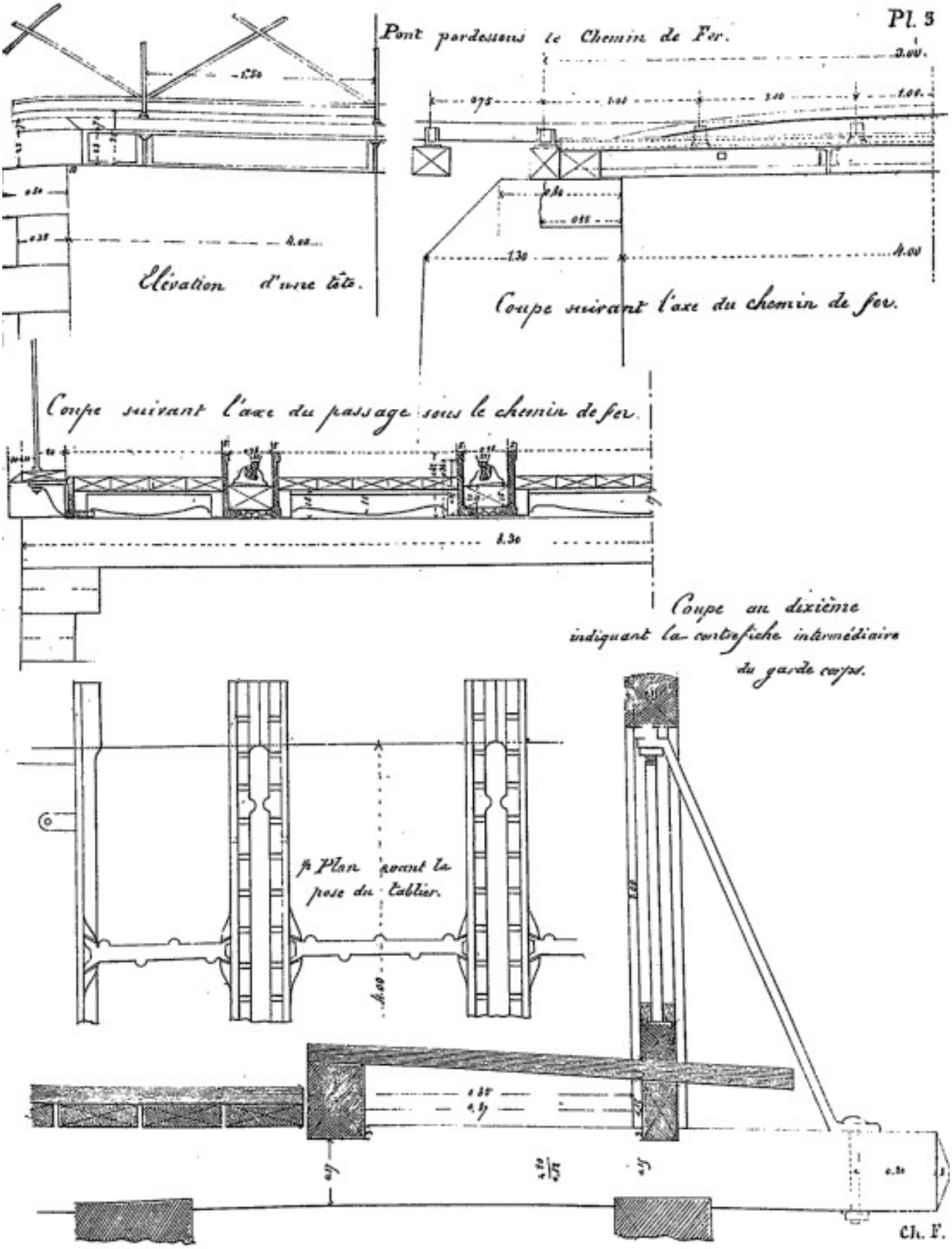
The average of all these numbers is 40,000 francs per Kilometer.

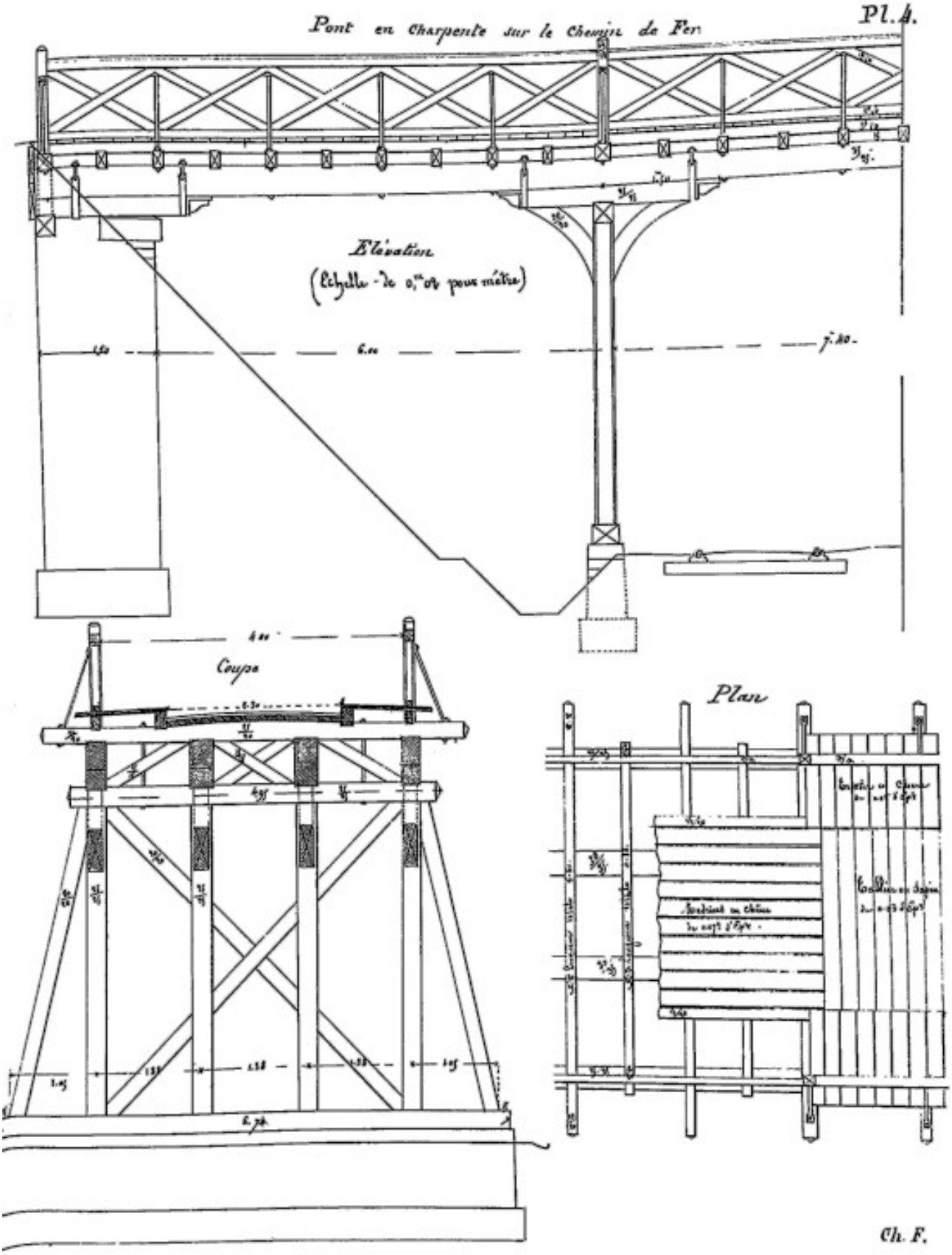
(*) Error in the manuscript: it is written 480 Km while the distance is 180 Km. The indicated price is therefore correct.



P.I
Chaudière et Foyer
voie de départ
4. 15
8. 70
Ch. F.

Pl. 2.
Demi profil pour le sable, lorsqu'on est en remblai.
fig. 3.
Demi profil pour le sable, lorsqu'on est en déblai.
fig. 4.
Demi profil pour la pierre cassée, lorsqu'on est en remblai.
fig. 5.
Demi profil pour la pierre cassée, lorsqu'on est en déblai.
fig. 6.
CH. F.


Pl. 3
Pont pardessus le Chemin de Fer.
Elévation d'une tête.
Coupe suivant l'axe du chemin de fer.
Coupe suivant l'axe du passage sous le chemin de fer.
Coupe au dixième
indiquant la contrefiche intermédiaire
du garde corps.
Plan avant la
pose du tablier.
Ch. F.


Pont en Charpente sur le Chemin de Fer
Pl. 4.
Élévation
(Echelle de 0,m 01 pour mètre)
Coupe
Plan
Ch. F.

Pl. 5.

Pont par dessous le Chemin de Fer.

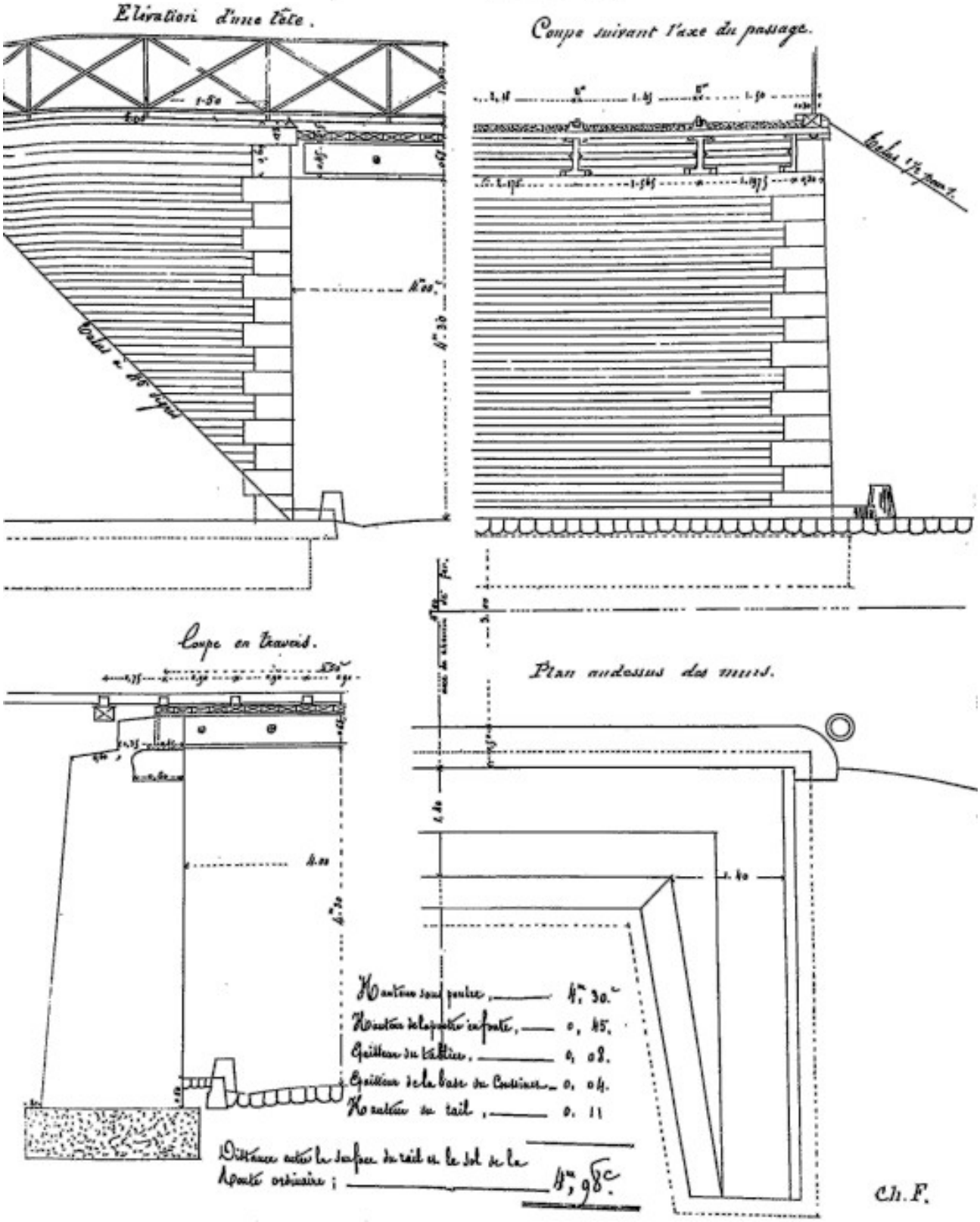
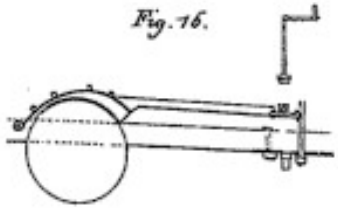


Fig. 18.

Pl. 6.

Fig. 16.



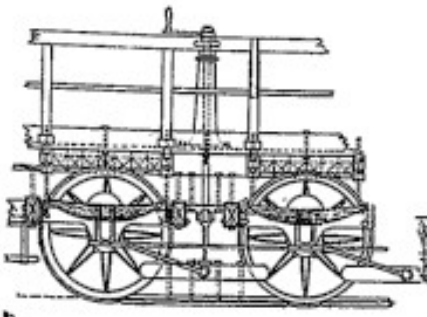


Fig. 17

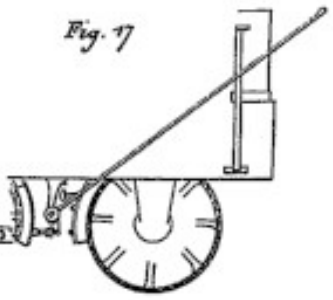


Fig. 16bis

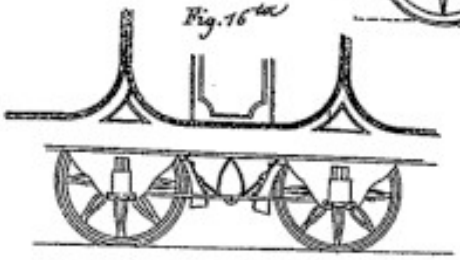


Fig. 19.

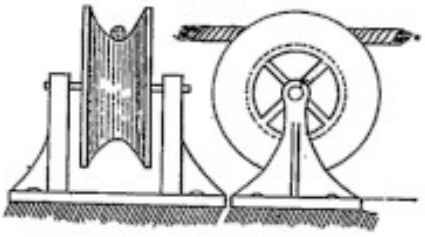


Fig. 16ter

Fig. 21.

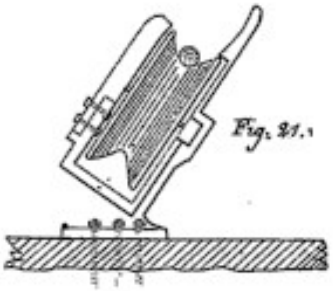
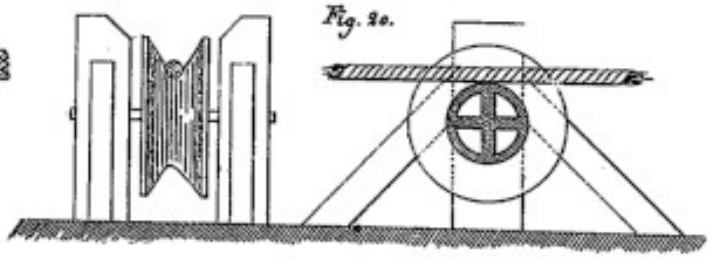


Fig. 20.



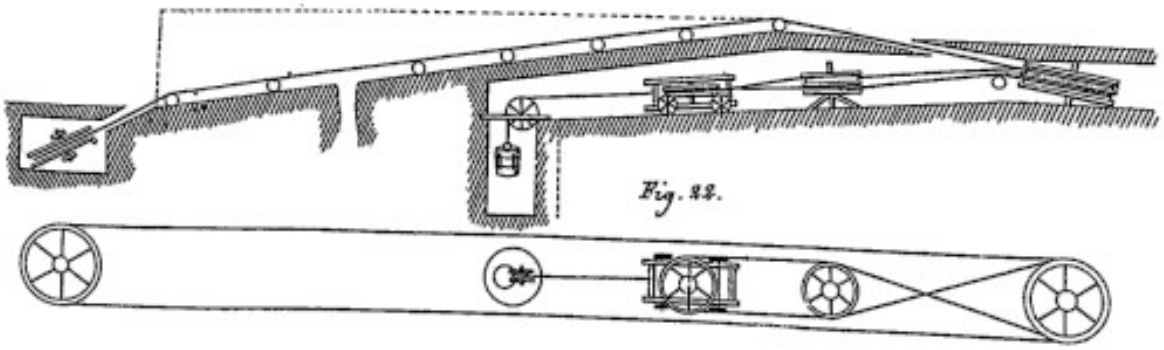


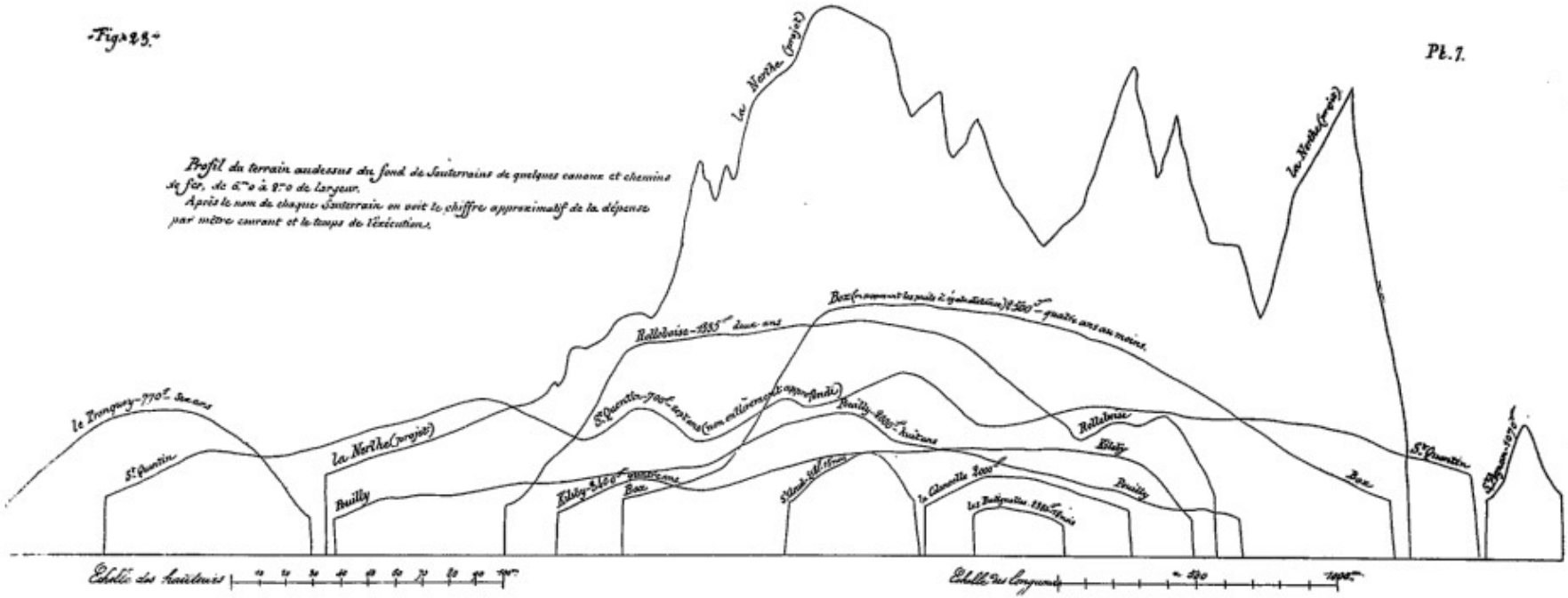
Fig. 22.

CH.R

Fig. 23.

Pl. 7.

Profil du terrain au dessus du fond de Souterrains de quelques canaux et chemins de fer, de 6.m 0 à 8.m 0 de largeur.
Après le nom de chaque Souterrain on voit le chiffre approximatif de la dépense par mètre courant et le temps de l'exécution.



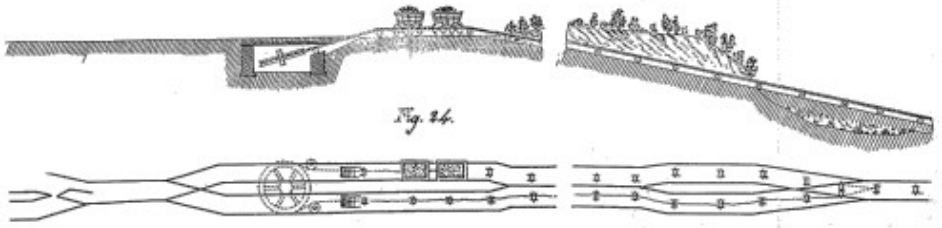
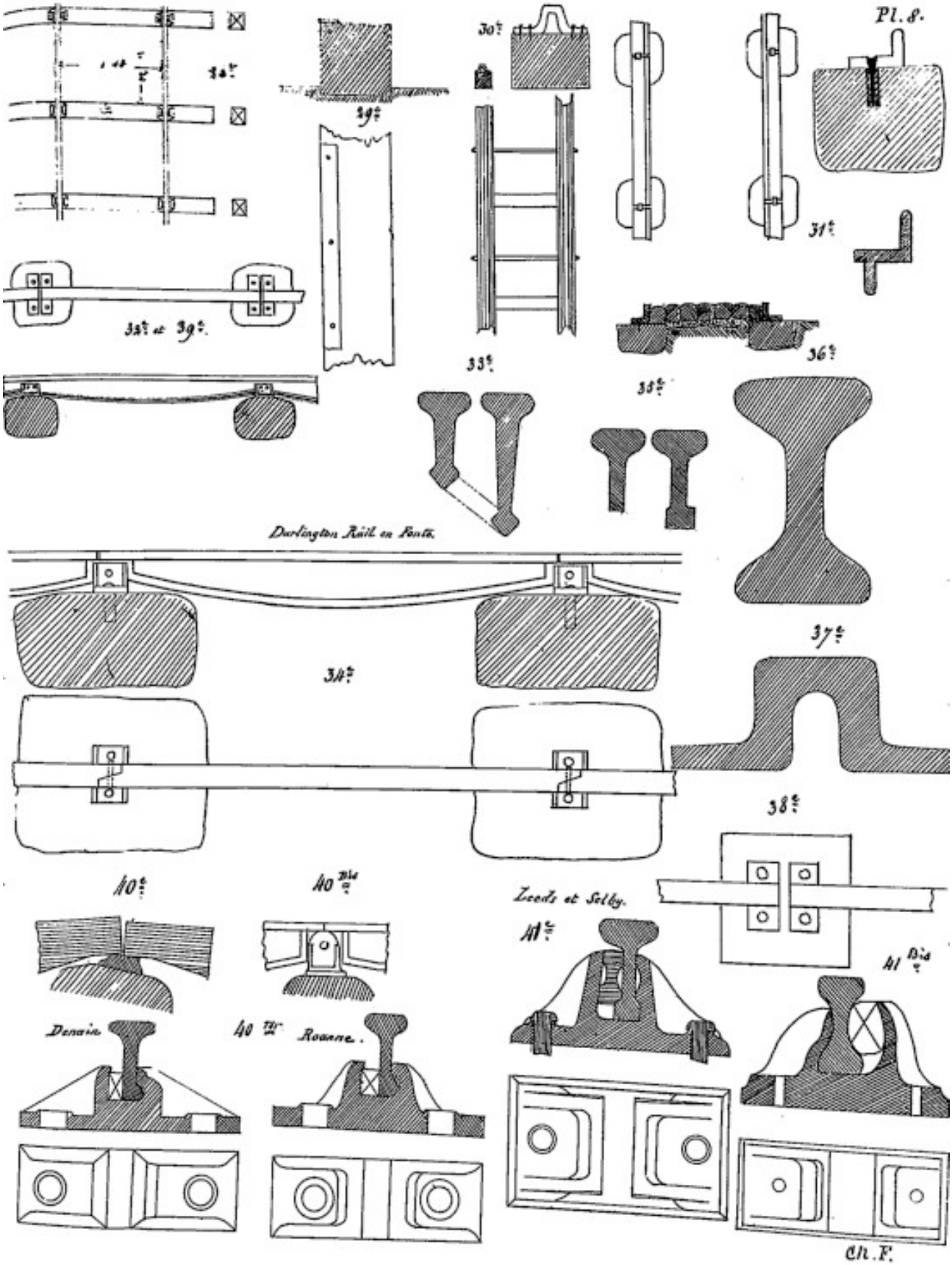


Fig. 24.

CH.P.


Pl. 8.
Darlington Rail en Fonte.
Leeds et Selby.
Denain
Roanne.
Ch. F.

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